JOURNAL OF THE AMERICAN WELDING SOCIETY

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Twelfth Fall Meeting American Welding Society

The twelfth Fall Meeting of the AMERICAN WELDING SOCIETY was held in Buffalo on October 3rd to 7th. Over 250 people attended the various sessions. As in previous years the Fall Meeting was arranged in connection with the Metal Congress and Welding Exposition.

From every point of view the Twelfth Fall Meeting was an outstanding success. The Welding Exposition consisted of about 20% of all of the exhibits at the Congress and as one member expressed it, they were all "dynamic." About 25 technical papers on a large variety of subjects were presented for discussion by eminent authorities in the welding field. A program was given in the last issue of the JOURNAL. Outstanding features included applications to the machinery industry, gas cutting, results of research, welding of non-ferrous metals, a merchandising session, qualification of welders, pressure vessels, structural steel and new developments in apparatus and materials.

The Miller Memorial Medal was presented to President McKibben at the annual banquet of the Society which was held on Wednesday evening. This banquet, followed by dancing, also formed the principal social event of the meeting. Special entertainment was provided for the ladies.

In order to save expense it was necessary to dispense with the stenotype reporter. Members of the Society who discussed papers are requested to prepare their discussions in writing and send them to headquarters. Other members who were unable to be present or desiring to present written discussions are urgently requested to send in such discussions as promptly as possible. This issue contains some of the papers presented at the Fall Meeting. Others have been printed in the September number; still others will be given in the November issue.

Miller Memorial Medal Award

At the Fall Dinner of the AMERICAN WELDING SOCIETY, President Frank P. McKibben was awarded the Samuel Wylie Miller Memorial Medal for his outstanding work in the development of the art of structural fusion welding. The award was made by Past-President J. H. Deppeler, acting in behalf of the Board of Trustees, consisting of Fred King, Chairman, J. H. Deppeler and C. A. McCune.

In presenting this award Mr. Deppeler called special attention to the accomplishments of Professor McKibben in a wide range of engineering fields. Professor McKibben is a bridge engineer of international reputation. He has acted as designing engineer and engineer of construction on drawbridges, elevated structures and buildings, railroad and highway bridges. Literally several thousand bridges have either been examined or designed by him. He was also consulting engineer for the Pennsylvania Water Supply Commission and City Engineer for the City of Schenectady.

His accomplishments in welding are no less remarkable. He has been connected with some twelve welded buildings since 1927. In 1922 he made the first shear test on fillet welds. He has delivered over a hundred addresses on structural steel welding and has written more than seventy-five articles on the same subject.

Prof. McKibben had more than twenty-two years teaching experience in M. I. T., Lehigh University and Union College.

His publications include "Steel Bridge Construction" in American Civil Engineers Handbook; "Concrete Arch Bridges" in Concrete—Plain and Reinforced; about 160 technical articles (other than those pertaining to welding) in scientific and technical journals and in publications of engineering societies.

Professor McKibben is also well known to the AMERICAN WELDING SOCIETY, having served as Senior Vice-President for two years, member of the Board of Directors and Executive Committee, Structural Steel Welding Committee, Structural Steel Welding Steering Committee, Committee on Building Codes and Committee on Pipe Welding.

He was elected President of the AMERICAN WELDING SOCIETY in April of this year.

Mr. Deppeler's comment that "it is remarkable how one man could have accomplished all this in a single lifetime" is particularly significant.

Science Provides Problems for All

(Reprinted from *Mechanical Engineering* Sept. 1932)

"Mark well the following sentence, ponder its implications, and quote it to your pessimistic friends who fear the havoc wrought by science. "That any one of intelligence should seek artificially to shirk the problems presented by the things which science has introduced into our midst is tantamount to saying that the human mind which has been capable of extracting these new things out of Nature's storehouse of the unknown is incapable of adapting them to beneficent purposes."

Thus spoke Dr. Frank B. Jewett, of the Bell Telephone Laboratories, at the dedication of the Hall of Science of the Century of Progress Exposition, Chicago, Ill., June 1, 1932 as reported in *Science* on July 8.

We live in an age in which science and engineering are more inextricably woven into the fabric of every-day life than at any other time in the history of human progress. Even those who dwell relatively remote from towns and cities depend in immeasurable ways on the proper functioning of devices and services that were unknown to the generations antedating the industrial revolution. Our habitual environments possess an artificiality, in the sense that they are man made and man sustained, that necessitates the most intelligent cooperation of interrelated individuals and organizations. Except in the outposts of civilization, where exists the self-sufficient individual?

Elsewhere in his address Dr. Jewett confesses that, in common with most folk, he saw nothing very much of the social problems when, more than twenty years ago, he was "completely obsessed with the apparently illimitable field of opportunity offered to those who wished to make science a life work." But knowledge brings power, and power, responsibility. The toys of the laboratory change the lives of millions, and the direction and velocity of human progress.

The Centennial Exposition in Philadelphia in 1876 brought to the people of this country an awakening knowledge of the productive usefulness of machinery, and stimulated extraordinary developments in industry. The World's Columbian Exposition in Chicago in 1892 provoked interest and developments in the field of electricity. Science is the keynote of the Century of Progress Exposition to be held next year in Chicago. Will its effect upon human progress be to bring to a majority of individuals a truer appreciation of the social aspects of science, a desire to make use of it for none but beneficent purposes, and a determination and courage to solve the problems that it places on Society?

IN MEMORIAM

The following resolution was adopted at a meeting of the Board of Directors of the AMERICAN WELDING SOCIETY on October 3rd in connection with the recent death of William A. Slack:

"Whereas, the passing of William A. Slack on June 21, 1932 is a distinct loss to the AMERICAN WELDING SOCIETY, and leaves with his friends and associates a feeling of deep and profound grief; and

"Whereas, his passing takes from us one whom we have long regarded as a true friend and a faithful worker for the welfare of our Society; and

"Whereas, for many years he has given willingly and enthusiastically of his time and energy to the problems and plans of the Society, which has benefited a great deal by his thoughtful counsel; and

"Whereas, it is the desire of this Society to record their high appreciation of his character and to express their deep sorrow for his loss; therefore, be it

"Resolved, That this resolution be spread upon the records of the AMERICAN WELDING SOCIETY, and a copy thereof sent to his bereaved family as an expression of our sympathy.

(*Signed*) E. P. MCKIBBEN
President
(*Signed*) M. M. KELLY
Secretary

SECTION ACTIVITIES

NEW YORK

The first meeting of the 1932–1933 session was held on September 20th. "Bronze Welding of Ferrous Metals," the subject of the meeting, included a discussion of the principles and practice of welding iron, steel, cast iron and malleable iron with bronze filler rods. Mr. Arthur R. Lytle, of the Union Carbide & Carbon Research Laboratories, Inc. presented a paper on "The Principles of Bronze Welding." Mr. J. A. Le Mieux of the Standard Sanitary Mfg. Co. spoke on "Some Modern Applications of Bronze Welding." Mr. W. S. Farr of the Air Reduction Sales Co. addressed the meeting on "Bronze Welding in Locomotive Maintenance and Repair."

LOS ANGELES

The September meeting of the Los Angeles Section was held on the 22nd, at the Mona Lisa Restaurant. Mr. Clayton M. Allen, Junior Electrical Engineer, Bureau of Power and Light, City of Los Angeles, presented a very interesting paper "Arc Welded Penstock," for San Francisquito Power Plant Number Two. This is the first all electric welded Penstock in the United States. Mr. Allen was in charge of field welding of this installation. Mr. Allen also showed pictures of the work in progress.

PHILADELPHIA

The first meeting of this season of the Philadelphia Section was held on September 19th. Mr. J. P. Morrissey of Crucible Steel Company gave a paper on "The Welding of Stainless Steels." The discussion after the presentation of his paper was particularly interesting.

The following is a tentative schedule of coming meetings:

October 17th—in the Auditorium of the Engineers Club, 8 o'clock. Mr. W. D. Halsey, Assistant Chief Engineer, Boiler Division, The Hartford Steam Boiler Inspection & Insurance Co., paper on "What Is a Good Weld." The following two will talk on "How to Weld to Meet the Boiler Code": Mr. R. F. Burke, of Heine Boiler Co., Inc., and Mr. T. M. Jackson, Electrical Engineer, Sun Shipbuilding & Dry Dock Company.
November 21st—"Railroad Welding."
January 17th—"Welds, Weld Tests and Welders."
February 20th—"Gas Welding."
March 20th—"Structural Steel Welding."
April 17th—"Shipyard Welding."

Statement of the Ownership, Management, Circulation, etc.

REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912

OF JOURNAL OF AMERICAN WELDING SOCIETY, published monthly at Easton, Pa., for October 1, 1932.

State of New York } ss.
County of New York }

Before me, a Notary Public in and for the State and County aforesaid, personally appeared William Spraragen, who, having been duly sworn according to law, deposes and says that he is the Editor of the Journal of the American Welding Society and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Name of — Post Office Address

Publisher, American Welding Society, 33 W. 39th St., New York, N. Y.
Editor, William Spraragen, 33 W. 39th St., New York, N. Y.
Managing Editor, William Spraragen, 33 W. 39th St., New York, N. Y.
Business Manager, M. M. Kelly, 33 W. 39th St., New York, N. Y.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)

American Welding Society, 33 W. 39th St., New York, N. Y.
F. P. McKibben, President, Black Gap, Pa.
M. M. Kelly, Secretary, 33 W. 39th St., New York, N. Y.
C. A. McCune, Treasurer, 25 West 43rd St., New York City.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state.)
None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

W. SPRARAGEN, Editor.

Sworn to and subscribed before me this 30th day of September, 1932.

(Seal) MARY T. HICKEY
Notary Public, New York County, New York County Clerk's No. 170.

New York County Register's No. 4H244
(My commission expires March 30, 1934)

Influence of a Magnetic Field Parallel to the Iron Arc on Welding

By F. R. HENSEL *and* W. A. MADDOX

†This paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 4, 1932. Messrs. Hensel and Maddox are connected with the Research Laboratories of the Westinghouse Elec. & Mfg. Co.

Introduction

MAGNETIC fields have been used in arc welding as a method of arc blow control.[1] The earliest patents were taken out by Bernados in 1888. The actions of various field arrangements on the arc have been recently described by R. W. Holt.[2] This paper describes the results of a systematic study of the effects of a longitudinal field upon the arc. Both D.C. and A.C. fields were studied in conjunction with D.C. arcs of straight and reversed polarity.

Test Set-Up and Test Material

The automatic welding equipment, control panel and recording meters, used for this study, are shown in Fig. 1. A close-up view of the coil used to obtain the longitudinal field and the automatic feed mechanism is seen in Fig. 2. The coil is 4 in. in diameter, $4^1/_4$ in. long and is wound with 400 turns of No. 10 B. & S. copper wire. The asbestos plate on the bottom is to protect the coil from splatter and heat radiated from the arc. The distance from the bottom of the coil to the work was kept constant ($3^7/_8$ in.) in all experiments. The coil was designed for use with either D.C. or A.C. The nozzle was built up to 4 pieces of tool steel to reduce eddy currents in the A.C. tests. A $^3/_{16}$-in. dust-coated electrode of approximately 0.10% carbon content was used. The majority of the tests were run with a table speed of 5 in. per minute. The welding current was supplied by a 60-volt, constant potential, 800 amp. D.C. generator. The test welds were deposited on low-carbon steel base plates.

[1] Bernados, U. S. A. Patents 388,245 and 388,246; Cutler and Marsden, U. S. A. Patent 1,580,020; Coffin, U. S. A. Patents 512,604 and 507,419; Chapman, U. S. A. Patent 1,640,437; Reid, U. S. A. Patent 1,246,658; Smith, U. S. A. Patents 1,792,243 and 1,840,330; Lincoln, U. S. A. Patent 1,840,600.

[2] "Methods of Controlling Arc Blow," *Welding Eng.*, March, pp. 40–42; April, pp. 44–46.

Test Results

1. Calibration of Coil.—The flux density measurements were made in the air gap between the electrode tip and the work. The gap was made $^3/_8$ in. for the following reasons: during welding with a $^3/_{16}$-in. electrode the gap is approximately $^3/_{16}$ in. and it was assumed that $^3/_{16}$ in. of the electrode was heated above the A_2 point (768° C.) where the material becomes non-magnetic. For the D.C. measurements a flux meter (calibrated ballistic galvanometer) was employed, while for the A.C. calibration a thermal type milliammeter was used. The measurements were carried out by C. S. Williams.[3] The calibration curves are shown in Fig. 3. The curves fall close together. Such discrepancy as appears is probably due to "skin effect" when operating on A.C. Measurements of the flux in the electrode showed flux densities in the neighborhood of 10 kilogausses. It is felt, however, that the flux in the air gap shown in Fig. 3 is mainly responsible for the effects described in this paper.

2. Deposition Efficiency.—In preliminary experiments it was found that by the application of a longitudinal D.C. field the deposition efficiency was decreased considerably. A systematic study of the effects of D.C. and A.C. fields gave the results shown by Fig. 5. The deposition efficiency was determined in the following manner: the automatic feed mechanism was used to deposit the beads shown in Fig. 4. The increase in the weight of the plate divided by the weight of the consumed electrode material was chosen as "deposition efficiency." After welding and before weighing the plates were cleaned of all splatter and oxides. The data were found to be accurate within plus or minus 0.5%

[3] Research Eng., Westinghouse Laboratories.

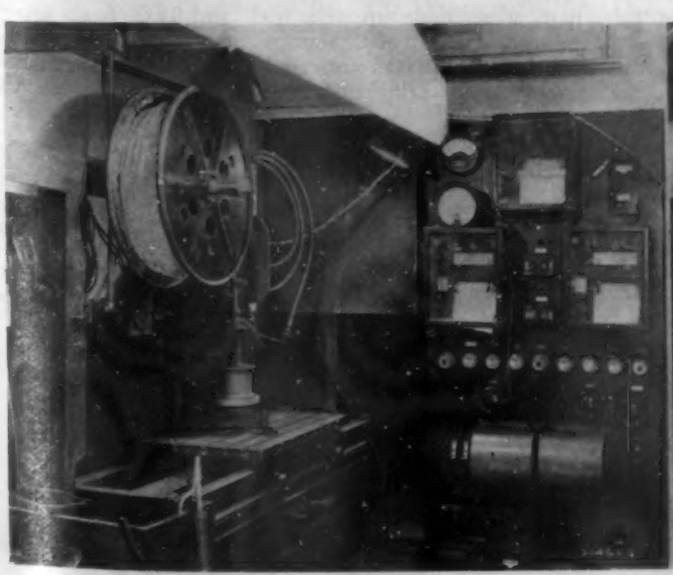


Fig. 1—Automatic Welding Equipment and Meters

Fig. 2—Automatic Feed Mechanism

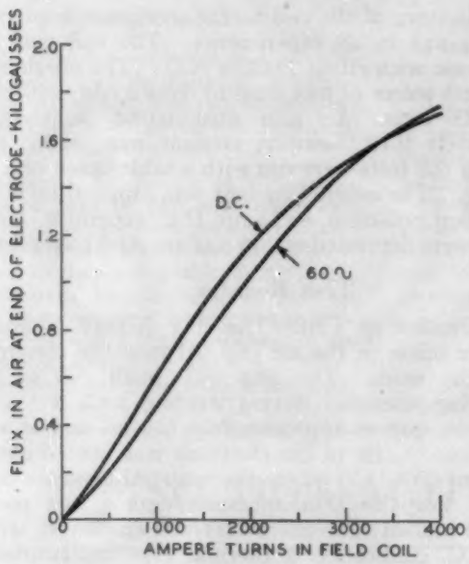


Fig. 3—Relation between Ampere Turns in Magnetizing Coil and Flux Density in the Air Gap between Electrode and Work

of the weight of deposited metal. The specimens shown in Fig. 4 were clamped in the center. The iron clamp caused the arc to be attracted toward it, causing the kink in the bead.

With the D.C. field a sharp decrease in deposition efficiency from 77% to 45% is observed near 1800 amp. turns. With more intense fields the deposition efficiency is slightly improved and reaches a value of approximately 57% at 5000 amp. turns.

With A.C. fields the deposition efficiency ranges near 75% up to a field strength caused by 2500 amp. turns which is practically the same as that obtained without any field.

The tests showed that about 2400 amp. turns for the A.C. field were sufficient to control the worst conditions of arc blow. From Fig. 5 it is evident that the deposition efficiency at that field strength is still as high as 75% and therefore satisfactory for welding, while the D.C. field necessary to control blow causes inefficient welding and excessive splattering which make this type of control impractical.

Welding with reversed polarity (Fig. 5) caused the decrease of deposition efficiency with increasing field strength to be more rapid. This is particularly noticeable with the D.C. field, while with the A.C. field at 2400 amp. turns the deposition efficiency is still in the neighborhood of 75%.

Selecting 2400 amp. turns to obtain the necessary field strength for the A.C. experiments a number of other variables were studied. It was found that: (1) a variation of the table speed from 2 to 8 in. per minute did not change the deposition efficiency appreciably (using a 17-volt arc and 275 amps.); (2) with a D.C. field the deposition efficiency was found to be a maximum when the electrode was held in a vertical position, while with the A.C. field an improvement in the deposition efficiency is obtained by advancing the electrode tip by tilting slightly (5–7°) in the direction of travel.

From the results plotted in Fig. 6 it is evident that the amperage in the range from 200–350 amps. for an A.C. field of 2400 amp. turns does not affect the deposition efficiency appreciably, although a maximum at about 275 amps. is quite noticeable. The ampere-deposition efficiency curve was run with a 17-volt arc except for the value at 400 amps., where an arc voltage of approximately 21 volts was necessary.

The curve showing the effect of voltage on the deposition efficiency was run at 275 amps. Increasing the voltage (which necessarily means an increase in arc length) lowers the deposition efficiency considerably. At 24 volts the deposition efficiency has decreased to 45%.

3. Spread and Penetration.—The results are shown in Fig. 7. With an A.C. field the spread is decreased and remains constant over a considerable range of field strength. With a D.C. field the spread increases with the field at a more or less constant rate. The average amount of spread with a D.C. field is approximately 2 mm. more than with an A.C. field. As would be expected, the penetration is greater with the application of an A.C. field as compared with the D.C. field. The difference amounts to approximately one millimeter for a total penetration of about 3 to 3.5 mm. As compared with no field there is practically no increase in penetration with an A.C. field and a decrease with the D.C. field.

4. Chemical and Gas Analyses.—To study the influence of A.C. and D.C. longitudinal fields on the nitrogen absorption of the deposit a number of weld pads were made up with A.C. and D.C. fields using a welding current of 275 amps. at 17 volts. In building up the pads it was noticed that with no or weak fields columnar crystallization of the deposited metal was very

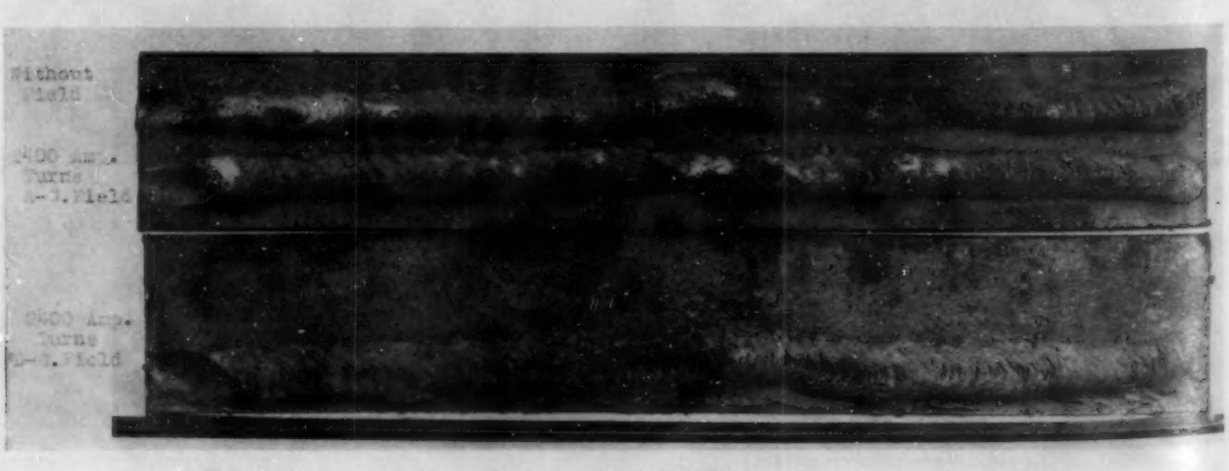


Fig. 4—Some of the Test Beads

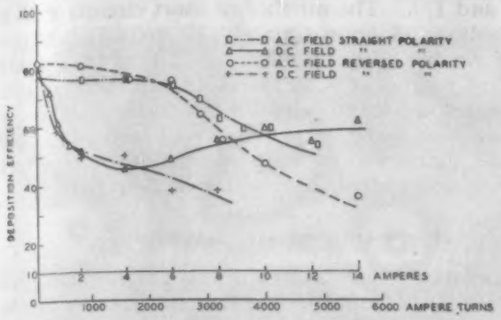


Fig. 5—Effect of A.C. and D.C. Fields on Deposition Efficiency for Straight Polarity and Reversed Polarity

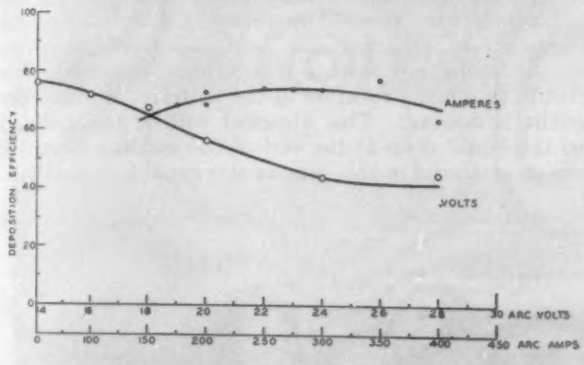


Fig. 6—Effect of Varying Volts and Amperes on Deposition Efficiency with a Constant A.C. Field of 2400 Ampere Turns

pronounced. It was less evident with D.C. fields above 2400 A.T. This is mostly due to the greater spread of the D.C. beads which allows heat from each succeeding layer to penetrate relatively further into the previous beads. There is also a possibility that the severe agitation of the molten pool that occurs with D.C. fields prevents the crystals from forming so regular a columnar arrangement. The porosity of the pads decreased with increasing field strength for both A.C. and D.C. fields. With fields caused by 2400 A.T. D.C. and 3000–4000 A.T. A.C. very sound deposits were obtained. The results of the nitrogen analyses according to Beiter's method[4] are collected in Table 1 and are plotted in Fig. 8. Nitrogen content evidently increases with the field strength. A very decided difference between the nitrogen absorption with A.C. control as compared with D.C. is evident. This is still more pronounced if instead of a 0.10% carbon dust-coated wire an uncoated rod with 0.02% carbon is used. In this case the nitrogen content with a D.C. field caused by about 2400 amp. turns went up to 0.17%, and, as would be expected, the tensile properties were therefore low, as shown by the following results of tensile tests:

Y. P. psi	U. S. psi	Elong. 1 in., %	Red. Area, %
30,600	49,300	11	11.6
31,200	49,500	11	10.1

Specimens of 0.25-in. test diameter and 1 in. gage length were used.

No such high nitrogen absorption was observed with A.C. fields. Check tests made with other wires and A.C. fields never gave nitrogen contents higher than 0.125 to 0.130%. Apart from nitrogen and possibly oxygen content the compositions of the deposits were not greatly influenced by the use of fields as is evident from Table 2:

[4] Journal of the American Welding Society, April 1932, p. 28.

Table 1—Effect of A.C. and D.C. Fields on the Nitrogen Content of Weld Deposits

A.T.	Nitrogen % with A.C. Field	Nitrogen % with D.C. Field
0	0.120	0.120
1200	0.123	0.131
2400	0.129	0.151
4000	0.134	0.149

Table 2—The Effect of A.C. and D.C. Fields on the Chemical Analysis of Weld Deposits

A.C. Field Amp. Turns	C	Mn	P	S	Si
0	0.02	0.10	0.010	0.026	0.008
1200	0.04	0.09	0.010	0.027	0.010
2400	0.03	0.09	0.009	0.027	0.006
4000	0.01	0.08	0.009	0.027	0.006
D.C. Field Amp. Turns					
0	0.02	0.10	0.010	0.026	0.008
1200	0.02	0.09	0.009	0.027	0.006
2400	0.02	0.07	0.009	0.028	0.008
4000	0.02	0.06	0.009	0.027	0.009

A definite decrease with increasing field strength is noticeable only in the manganese contents.

Oscillographic Studies

The current and voltage variations while operating with and without field were recorded with a Westinghouse portable oscillograph. Some characteristic results are reproduced in Figs. 9 to 12.

The changes of the arc characteristics are slight.

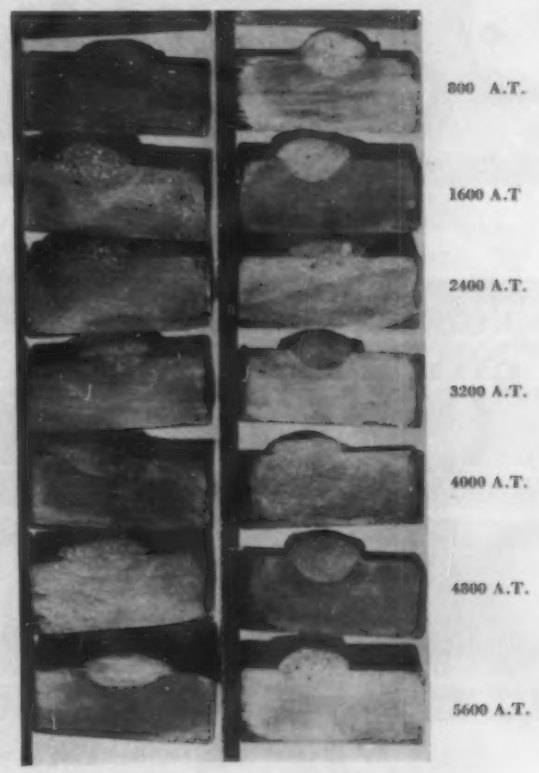


Fig. 7—Cross Section of Beads Showing Spread and Penetration

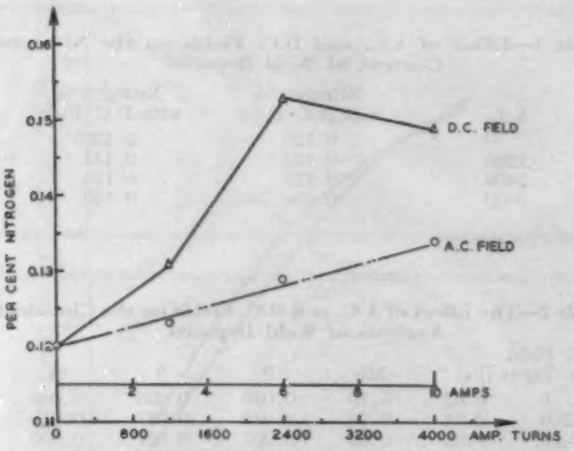


Fig. 8—The Effect of A.C. and D.C. Fields on the Nitrogen Content of Metallic Electrode Arc Deposits

With D.C. fields a definite increase in arc voltage was found, amounting to 1–3 volts (Figs. 11 and 12). With higher arc voltages both A.C. and D.C. fields stabilize the arc as evident from the smoother voltage curves (Figs. 10 and 12). The number of short circuits with a low arc voltage of approximately 17 volts is between 10–15 per second (Figs. 9 and 11). The short circuits more or less disappear with increasing arc voltage due to the greater arc length and the mechanical difficulty of shorting the wider gaps (Figs. 10 and 12). No appreciable difference between the number of short circuits with and without fields could be detected.

Discussion of the Results

The experiments have shown that a longitudinal field produces a definite influence on the stabilization of the arc and on the metallurgical characteristics of the deposit. The oscillographic measurements, however, did not reveal electrical characteristics which might be responsible for this. Apparently[5] the longitudinal component of the magnetic field can have no effect, but the radial component might have a considerable effect in producing rotation of the material in which the current is flowing. This material will be the gas and also the liquid drop at the end of the welding electrode since the material in this drop is also capable of rotation.

[5] Communication from Dr. J. Slepian, Consulting Eng., Westinghouse Research Laboratories.

Fig. 9—17-Volt Arc with A.C. Longitudinal Field (2400 A.T.)

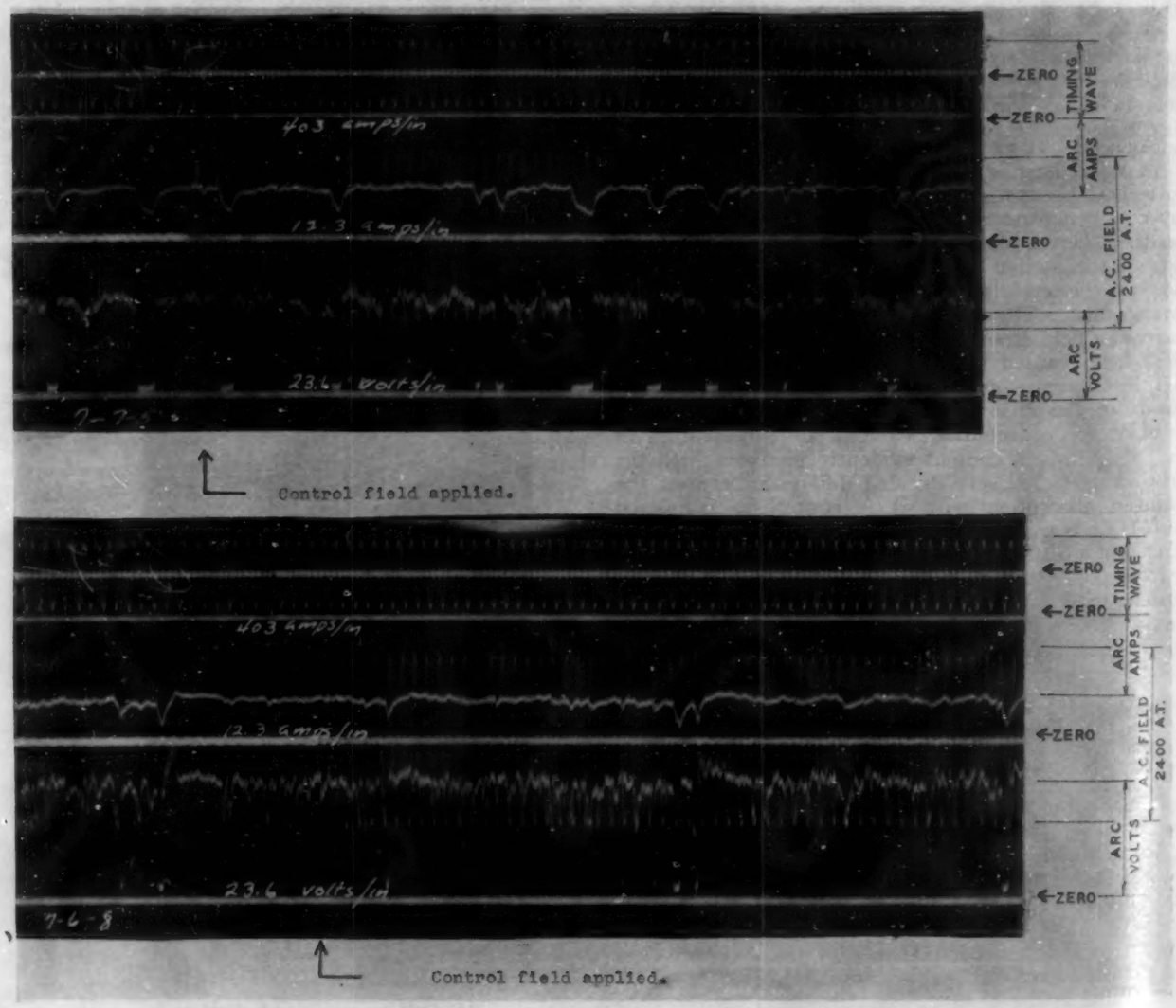


Fig. 10—24-Volt Arc with A.C. Longitudinal Field (2400 A.T.)

Fig. 11—17-Volt Arc with D.C. Longitudinal Field

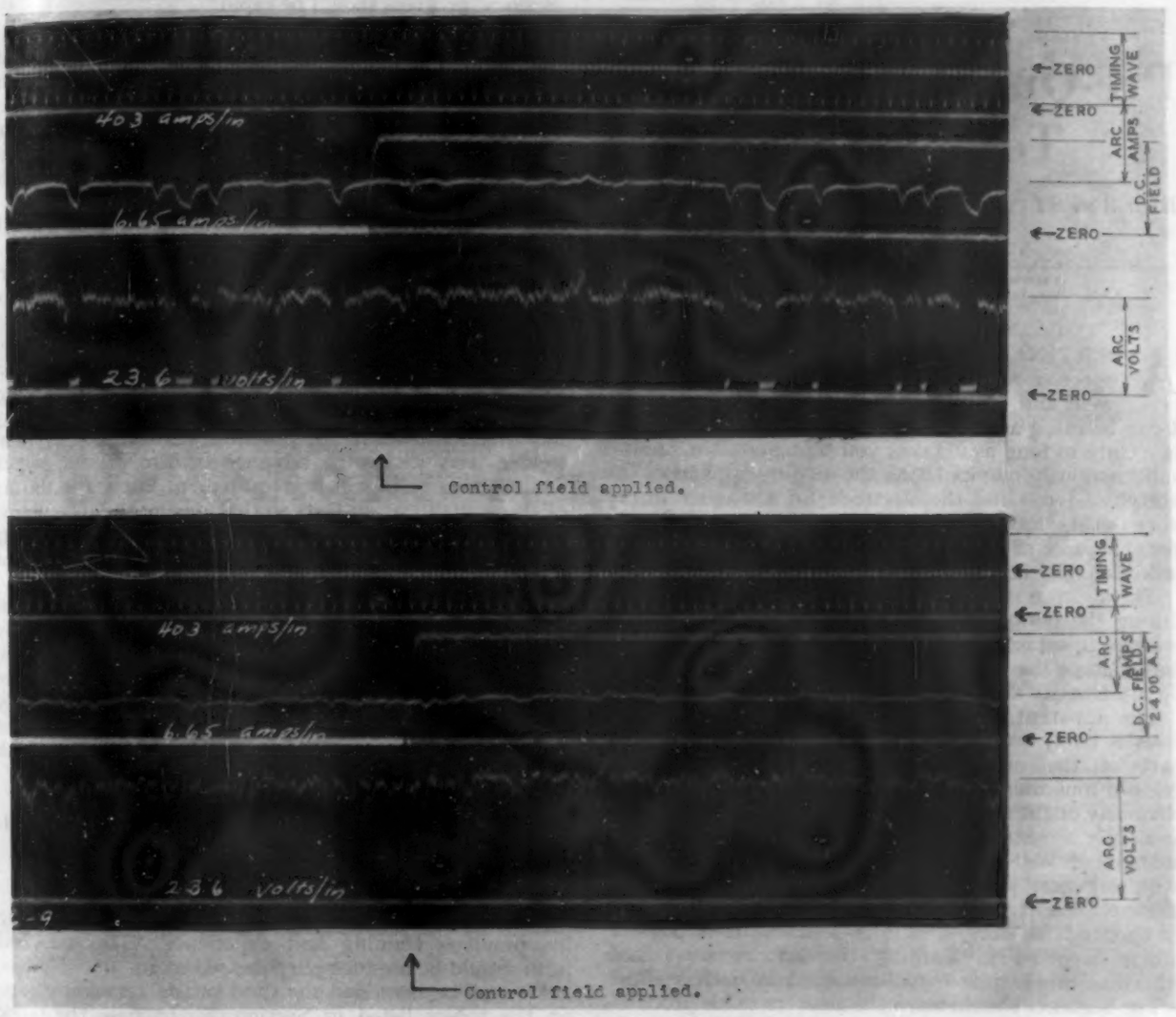


Fig. 12—24-Volt Arc with D.C. Longitudinal Field

The rotation of the gas and the liquid drop may produce a stabilizing effect.

We have seen that the drops fell at the rate of 10 to 15 per second. Therefore the drops must receive their angular velocity with a D.C. field in approximately $^1/_{15}$ second. By using an alternating field the drop would reverse its direction of rotation each half cycle. Hence, with 60 cycles there would be only $^1/_{120}$ second for the drop to receive its angular velocity. To give the same angular velocity in this time, therefore, it would be necessary to use a field 10 times as great as in the D.C. case.

Angular velocities of the order of 1000 r.p.m. might be obtained which may be expected to stabilize the drop considerably and keep it from being deflected sidewise while it is forming. After leaving the electrode it may be expected to drop straight down with only a small sidewise deflection due to any unbalanced forces at the moment of its breaking away. The gyroscopic stabilization of the drop, while it is still attached to the electrode, may be expected to make the arc itself more stable because the swinging of the drop from side to side in the absence of this stabilization would also carry the cathode spot at its terminal from side to side and this would change the direction of the vapor blast coming from the boiling metal at the cathode spot and thus tend to make violent changes in the direction of the arc and violent mechanical reactions upon the drop itself.

Conclusions

1. The phenomenon of arc blow can be largely corrected by means of A.C. and D.C. longitudinal fields.
2. The deposition efficiency has been found to be a function of the field intensity. With stronger fields the deposition efficiency decreases. This decrease is much more pronounced with D.C. than with A.C. fields. It has been found possible to correct blow with an A.C. field and still have about 70% deposition efficiency.
3. Spread and penetration are not affected appreciably with A.C. fields, while with D.C. fields the spread is increased and the penetration decreased.
4. The nitrogen absorption with D.C. fields is higher than with A.C. fields, although some increase of nitrogen pick-up with increasing A.C. field was evident.
5. Oscillograms show that the application of a longitudinal field only slightly changes the electrical characteristics of the arc.
6. Gyroscopic stabilization of the arc is discussed.

Pre-Qualification Tests for Welders

By ERNEST LUNN

†This paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 5, 1932, by Mr. Lunn, Consulting Engineer.

A PERTINENT question usually asked by a prospective welder is, "How long will it take me to weld and what qualifications must I have before I can be rated as a first-class welder?" A good answer is, "Only so long as it takes you to acquire the habit of subconsciously manipulating the welding appliances (the acetylene torch and the electrode) in a manner to produce welds having certain characteristics which experience has shown are required in welds free from objectionable faults."

The most trying time in a man's welding career is during the period when he is endeavoring to train his muscles to act in ways to which they are not accustomed, and to force them to perform at once, as they ordinarily do after weeks and months of patient effort.

The apparent simplicity of the various welding processes is likely to lead to erroneous conclusions on the part of the uninitiated operator. Directing undeveloped muscular action by will power to produce what obviously ought to be done in making good welds is not as simple a matter as it might seem to be. A certain amount of well-directed effort must be expended in acquiring near perfection in welding and it is not an accomplishment that can be learned from observation or upon advice only, and it is desirable that physical efforts involved in learning the art be supervised, otherwise much time may be wasted in useless effort.

The beginner should learn the answers to his problems as he progresses with his exercises, and strive to make welds that meet requirements, starting with simple problems and advancing to the more difficult, as proficiency is acquired. He should learn to judge weld metal quality, to some extent, from the appearance of fractured welds made by him, and should include in his studies the strength and resistance of welds in order to better understand the relation of his work and that of an expert whose rating he is endeavoring to acquire. He should also approach the many problems confronting him with an appreciation of the responsibilities which will come to his lot once he has become a qualified welder.

It is well for the beginner to make a start by depositing metal in the easiest way possible, and under the direction of an experienced welder who should know how to instruct others. This latter provision is to keep the beginner from forming wrong habits in handling the torch and electrode; habits which, if persisted in, will retard his progress. Upon acquiring ability to make a sound deposit, further progress should not be difficult.

The beginner can congratulate himself when he is able to butt weld two pieces of mild steel, say, 6 in. long, 2 in. wide and $^1/_4$ in. thick, lying in a flat position, and have the weld metal present a sound appearance when fractured. Another significant period in his progress is when he is capable of making a good fillet weld of the simplest form. Having acquired that proficiency, progress should be rapid.

As plate and structural steel welding head the list in volume, it is logical that a beginner should qualify for the type of welds most generally used in such fabrication.

When welders are being qualified for pipe work, sheet metal, thin wall tubing, non-ferrous metal, etc., the operators should be examined as to their ability to make good welds of the type to be used in the particular field concerned.

The tests referred to later would be pertinent as qualitative, but not as quantitative tests.

Decision as to whether a man is fit to work on a certain job is not answered by how long he has gone to school or for whom he has worked, but by his ability to make welds that the particular job requires. It is desirable for the employer who wishes to qualify his welders to have as a guide, a typical method of qualifying, so that his own procedure may not be lacking in any important detail. It is also desirable for the student welder who wishes to advance into work for which qualification tests will be required, to know the nature of these qualification tests so that during the instruction period he can check his progress against the testing program which he knows must come before he can be accepted as a welder on important work.

The purpose in presenting the following specifications is to recommend a simple, standard method whereby the qualifications of an operator to make sound fusion welds may be determined at minimum expense. Where established Codes have been found to satisfactorily cover the qualification of operators welding in special fields, it is recommended that the regulations of such Codes be followed.

RECOMMENDED SPECIFICATIONS FOR PRE-QUALIFICATION TESTS FOR WELDERS

Section I—Requirements

The applicant shall furnish full information regarding his previous training and experience. The attached form should be used for purposes of record.

He shall be examined and show satisfactory knowledge on the topics listed in Section 2. In case the work contemplated is of an usual nature, he shall also be examined on such special topics as pertain thereto. The result of this examination should be recorded on the attached form.

He shall prepare welded specimens in accordance with Section 3 which shall comply with the tests specified therein. In case the work contemplated will involve the making of butt welds, Test 1 shall be used, and if the butt welds are to occur in important work, such as heavy plate construction, boilers or other pressure vessels, Test 3 shall also be used. In case the work contemplated will involve the making of fillet welds, Test 2 shall be used, and in case the fillet welds are to occur in important work, such as structural steel, Test 4 shall also be used. Tests 1 and 2 may be made prior to Tests 3 and 4 in order to save unnecessary expense in case the former do not result satisfactorily. Entry should be made on the attached form as to whether the Quality Test is satisfactory, and the strengths developed in the Tensile Test should be recorded on this form.

Section II—Topics for Examination

For Gas and Arc Welders

The meaning of "penetration."
The meaning of "fusion."

RECORD OF WELDER'S EXPERIENCE

COMPANY _____

PLANT _____

DATE _____

NAME _____ ADDRESS _____

AGE _____ NATIONALITY _____

EXPERIENCE: (Check)

	Aircraft Tubing		Low Pressure Pipe		Small Diameter Pipe
	Boiler Factory		Oil Refinery		Structural Steel
	Boiler Repair Shop		Plain Carbon Steel Tubing		Tank Factory
	Heavy Plate Work		Pressure Vessel Work		Flat Welding
	High Pressure Pipe		Railroad		Vertical Welding
	Job Welding Shop		Sheet Metal		Overhead Welding
	Large Diameter Pipe		Ship Yard		

NATURE AND PLACE OF FIRST INSTRUCTION IN WELDING _____

EXAMINATIONS PASSED _____

CERTIFICATE OR PERMIT _____

TYPES OF EQUIPMENT USED _____ TYPES OF WELDING ROD USED _____

SPECIALTY, IF ANY? _____

GENERAL EDUCATION _____

RECORD OF WELDER'S QUALIFICATION TEST

THEORETICAL KNOWLEDGE _____

QUALITY TEST-BUTT WELD _____ QUALITY TEST-FILLET WELD _____

TENSILE TEST - BUTT WELD			TENSILE TEST - FILLET WELD	
Thickness of Plates	STRENGTH (Lbs. per Sq.In.)		Thickness of Bars	STRENGTH (Lbs.per Lin.In.)
	Minimum	Average		

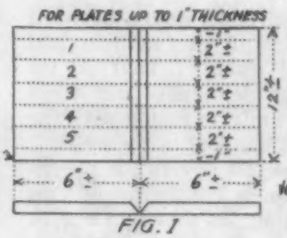


FIG. 1

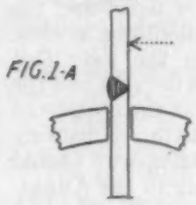


FIG. 1-A

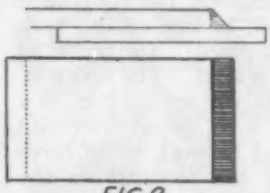
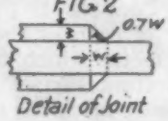
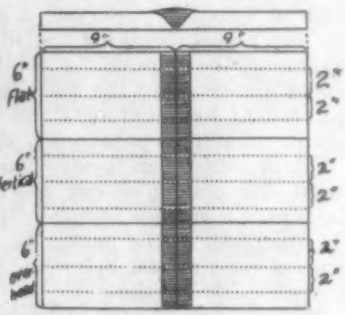
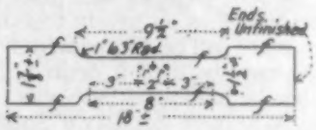


FIG 2



Detail of Joint





FOR PLATES UP TO 1" THICKNESS
FIG 3

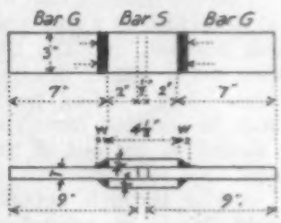


FIG 4

The meaning of "burned metal."
The value of reinforcement.

For Gas Welders

The meaning of "oxide inclusions."
Safeguarding the handling of cylinders, regulators, torches, carbide, acetylene, oxygen and the open flame.

For Arc Welders

Adjustment of regulating devices.
Effect of length of arc.
Relation between wire diameters and current strength.
Protection of themselves and others from radiations.

Section III—Tests

General.—Plates used in making specimens shall consist of low-carbon open-hearth steel, not exceeding 65,000 lb per sq. in. ultimate tensile strength, whose surfaces shall be thoroughly cleaned and prepared for welding, except in cases where the operator is striving to qualify for a particular job in which other metal is to be welded, in which case welding wire suitable for the purpose should be used in making the qualifying welds. The specimens (required for Tests 1, 2 and 4) shall be welded in whatever position or positions (flat, vertical or overhead) will occur in the work contemplated. (The specimen for Test 3 shall be welded as specified below.) During the making of all test specimens the welding technique of the applicant should be observed. In the case of arc welding, he should be able to hold an arc of proper length in order to secure proper penetration and fusion, to select and maintain a proper current and to handle the electrode with a regular movement. In the case of gas welding, he should keep the welding tip clean, use a soft, neutral flame, secure proper penetration, float out the oxides, fuse the welding rod thoroughly with the base metal.

Quality Test—Butt Weld—This test covers the preparation and testing of one specimen consisting of two plates each about 6 in. x 12 in., connected edgewise by means of a single Vee butt weld as shown in Fig. 1. The thickness of the plate, the angle of bevel and the depth of the shoulder below the bevel should be as close as practicable to those to be used on the job. Plates should be tacked or placed in position so as to insure that they will be reasonably flat after welding. Gas welders may make the weld with a single pass, but arc welders should be required to make the weld in two passes, the surface of each deposited layer being carefully cleaned with a wire brush or by chipping before applying the second layer. In both cases, the weld reinforcement should be 20% of the plate thickness. The weld should be made on the long dimension of the plates so that five coupons 2 in. wide can be secured. Only four of the coupons need be tested, but these should be selected so as to include at least one of the outside coupons.

The coupons cut from each specimen should be bent in a vise with the bottom of the Vee on the outside in such a manner as to break through the weld metal (Fig. 1-*A*). The weld metal should then be examined for cleanliness of deposit, penetration, fusion and soundness.

Quality Test—Fillet Weld.—This test covers the preparation and testing of one specimen consisting of two plates each about 4 in. or 5 in. wide, connected by means of a fillet weld as shown in Fig. 2. The thickness of the plate should be the same as that of the material to be used on the job.

The specimen should be prepared by laying one plate over the other so that the end of the top plate is set back from the end of the bottom plate a distance equal to four times the thickness of the plate, a full fillet weld being deposited in the corner thus made. The weld

shall be tested by inserting a suitable wedge between the two plates, breaking the weld in this manner and examining the deposit for weld quality; that is, for proper dimension of the fillet, for cleanliness and dense structure of deposited metal, for uniform fusion with the base metal and for penetration at the root of the weld.

Tensile Test—Butt Weld.—This test covers the preparation and testing of one specimen consisting of two plates each 9 in. wide and 18 in. long, as shown in Fig. 3. The thickness of the plate, the angle of bevel and the depth of the shoulder below the bevel should be as close as practicable to those to be used on the job. One of the long edges of each plate should be beveled and the beveled edges set nearly together, so that the completed test plate will be approximately 18 in. x 18 in. A backing strip may be used if desired. The welding wire should either be mild steel bare-wire conforming to the AMERICAN WELDING SOCIETY'S Specifications, the equivalent thereto, or the same type that will be used on the work for which the operator is being examined. The record of the test should indicate that wire is used. The first 6 in. should be welded in a flat position, the second 6 in. in a vertical position, and the third 6 in. in an overhead position, if the welder is expected to work in all three positions. Any welding position not required on the job may be omitted from the test. Coupons $1^3/_4$ in. wide should be cut out of the center of each of these sections. All reinforcement and all metal which has been worked through beyond the bottom surface of the weld should be ground or machined off after the weld is completed. Each coupon should then be prepared as specified by the AMERICAN WELDING SOCIETY Committee on Standard Tests for Welds, a copy of which may be found.

These coupons when pulled in a tensile testing machine should show a minimum ultimate strength (in pounds per square inch of throat) of 85% of the plate strength, with an average of 90% of the plate strength for each pair. The plate strength may be determined either by test or from mill report.

Tensile Test—Fillet Weld.—This test covers the preparation and testing of one specimen consisting of two grip bars each 3 in. wide, 9 in. long and $^1/_2$ in., $^3/_4$ in. or 1 in. thick, and two strap bars each 3 in. wide, $4^1/_2$ in. long and $^1/_4$ in., $^3/_8$ in. or $^1/_2$ in. thick, respectively. The bars are to be welded as shown in Fig. 4. Each leg of the weld should be the same as the thickness of the strap. In the case of arc welds a single layer should be used for the two thinner specimens and two layers for the thicker specimen. The ends of the grip bars in each case should be separated about $^1/_2$ in. All the pieces should be flattened if necessary and clamped to obtain perfect alignment and contact. Tack welding of the assembly is recommended. When pulled in the testing machine, the minimum load requirement should be 8000, 12,000 and 16,000 lb. per linear inch of weld, respectively.

The material in the foregoing recommendations has been compiled from the minutes of the meetings of the Committee on Qualification Tests for Welders of the AMERICAN WELDING SOCIETY of which the writer was chairman, and an acknowledgment is hereby made to all members of that committee for their splendid co-operation in its work.

A Corrosion-Fatigue Study of Welded Low-Carbon Steel

By WILBER E. HARVEY *and* F. JEROME WHITNEY, JR.

†This paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 4, 1932. Prof. Harvey is Assistant Professor, Department of Metallurgical Engineering, Lehigh University. Mr. Whitney, Jr., is Graduate Student, 1932, Department of Metallurgical Engineering, Lehigh University. Report presented to the Fundamental Research Committee of the American Bureau of Welding.

Corrosion Fatigue

DR. D. J. McADAM, JR., of the Naval Engineering Experiment Station, was the pioneer in the study of repeated stresses as affected by corrosion. He reported that there is no plain carbon or alloy steel, other than the so-called stainless variety, which has a corrosion-fatigue value exceeding 25,000 lb. per sq. in. By corrosion-fatigue value or limit is meant the highest stress which a metal will endure indefinitely when subjected to repeated stresses and exposed simultaneously to the corrosive influence of a stream of water. "Indefinitely" is often accepted as meaning 10,000,000 cycles of stress under alternating flexure tests on ferrous materials. The corrosion-fatigue limit of a metal or alloy, of course, cannot be a constant but only becomes a definite value for one particular corrosive medium. For example, the corrosion-fatigue limit of a steel exposed to the corrosive action of salt water is generally lower than that when exposed to fresh water which has a high content of carbonate. The carbonate which is precipitated upon the surface of the steel after a certain time seems to form a coating on the steel which is protective to the underlying metal. The protection is probably due to the imperviousness of the carbonate coating to the water which is flowing over it.

The composition of the steel, its heat treatment and any previous cold-working done upon it seem to have no effect upon the corrosion-fatigue limit of the steel except as they affect the corrosion resistance of the

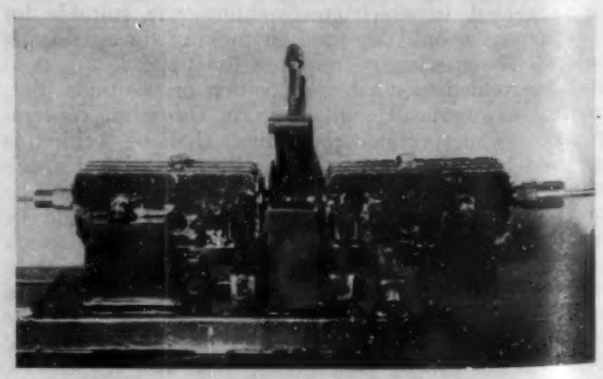


Fig. 1—Photograph of Corrosion-Fatigue Testing Machine

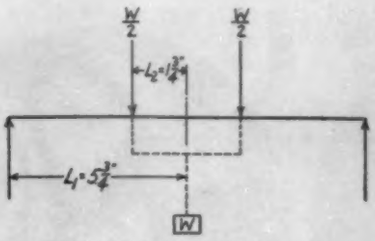


Fig. 2

alloy. There does not seem to be any relation between the corrosion-fatigue limit of a metal or alloy and any of its mechanical properties. The fatigue limit of the metal under water seems correlated only with the electrolytic solution pressure of that metal or alloy for that particular corroding medium. It does appear, however, that the electrolytic solution pressure of a metal under stress differs from the electrolytic solution pressure of the truly unstressed metal. The tendency of a stressed metal to dissolve is not measured by its solution pressure in the unstrained condition but by an electrolytic solution pressure increased probably in the proportion that the stress has been raised. The direct relationship between stress and solution pressure has not been determined as yet, but it is known that as the stress increases the solution pressure also increases. When corrosion cracks are formed as the result of original corrosion pits, and if these corrosion cracks increase the local stress and diminish the safe area of the sound metal to such a degree that the actual stress in the sound metal at the base of the corrosion cracks exceeds the endurance limit of the metal in air, then failure occurs, even though the nominal designed stress may not be exceeded. For stresses well below the corrosion-fatigue limit, the stress is never high enough to cause ultimate failure. At stresses below the corrosion-fatigue limit one or two things may occur to prevent the ultimate failure of the metal. Either a carbonate coating fills the corrosion cracks and prevents the water from entering to continue its eating action on the metal or else there is a strengthening effect at the base of the corrosion cracks in the steel due to a cold-working effect. This strengthening effect renders the steel less vulnerable to the effects of fatigue. It is very probable that there may be a combined effect of these two conditions.

The corrosion-fatigue limit range for all steels other than the so-called stainless irons and steels lies between 12,000 and 25,000 lb. per sq. in. It was also pointed out by Dr. McAdam that in the lower range are found the pearlitic low-carbon steels and the sorbitic higher carbon steels. At the upper limit of the range the sorbitic low-carbon steels are found and also the pearlitic higher carbon steels. Alloying elements do not affect this range other than they may affect the corrosion resistance of the alloy itself. Even copper, which is added to steel in slight quantities to aid in the prevention of ordinary atmospheric corrosion, has practically no effect upon the corrosion-fatigue resistance of steel.

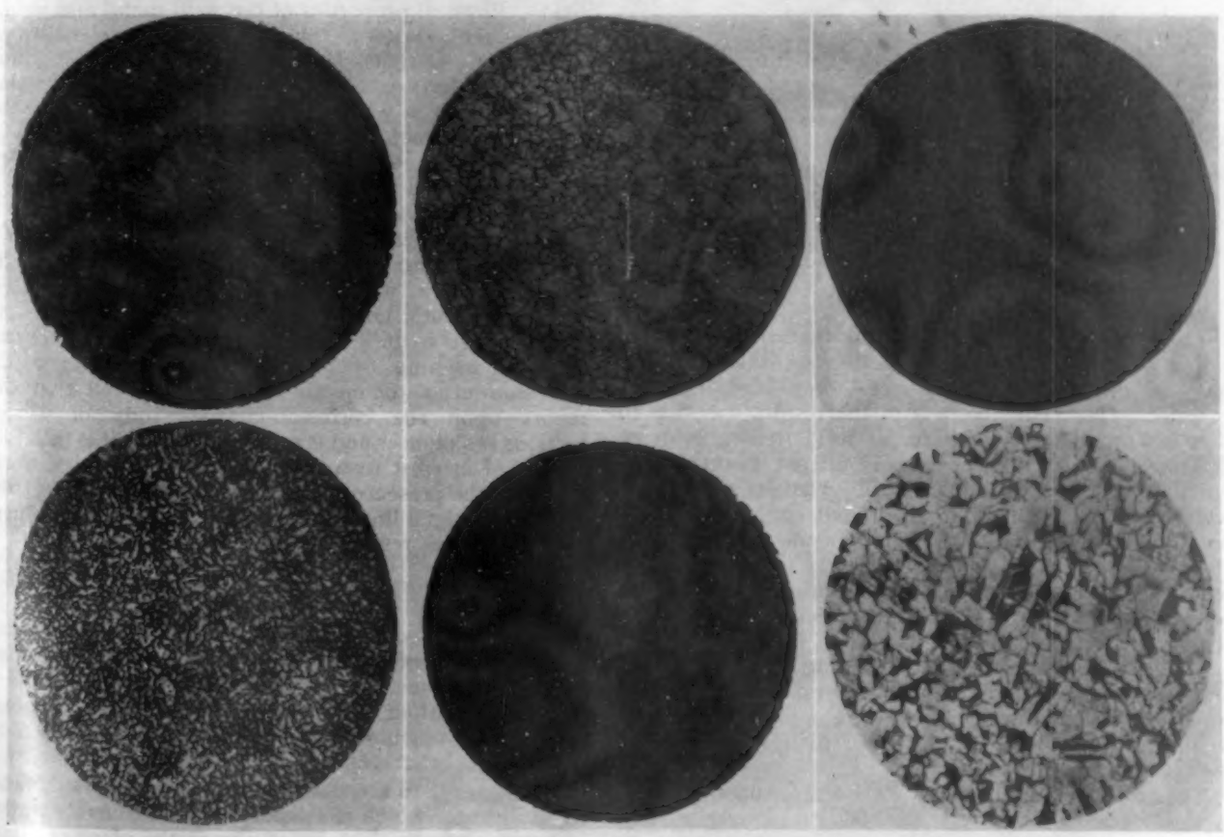
The high chromium content irons and steels have

Fig. 3—Covered Metal Arc Weld

Etchant—5% Nital
(a) Weld

(b) Junction

Magnified 100 diameters
(c) Parent metal

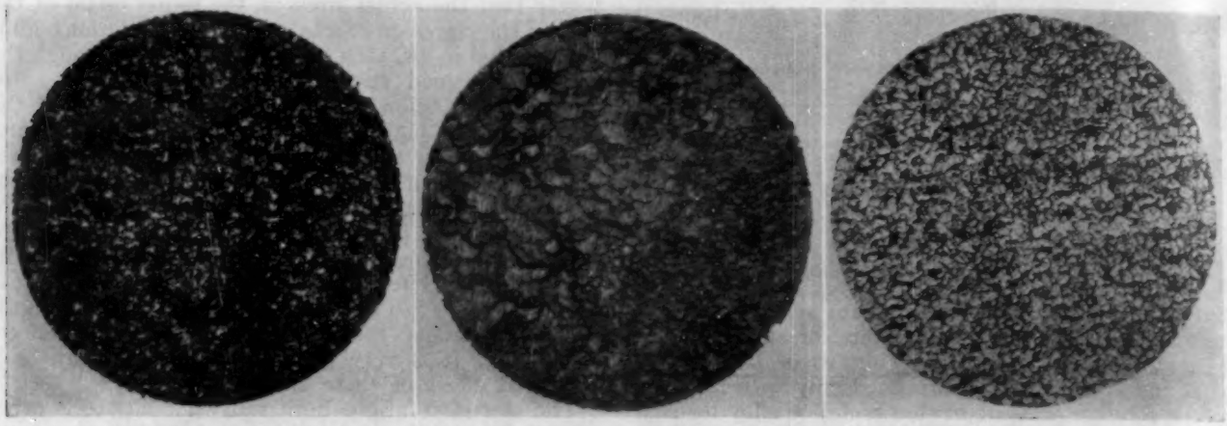


(a) Weld
Etchant—5% Nital

(b) Junction

(c) Parent metal
Magnified 100 diameters

Fig. 4—Bare-Wire Arc welds

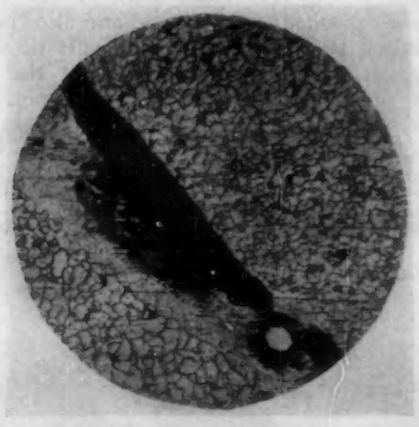


(a) Weld
Etchant—5% Nital

(b) Junction

(c) Parent metal
Magnified 100 diameters

Fig. 5—Atomic Hydrogen Welds



(d) Junction with impurity

been reported to have corrosion-fatigue ranges of 30,000–40,000 lb. per sq. in. This doubles the average value obtained with the ordinary steels but the cost of the corrosion resistant steels limits their use.[1]

Testing of Welds

Physical test results of welded material for many years were ineffective as data representative of the physical properties of weld metal or welded metal in general. The ineffectiveness of the results was due to the "irreproducibility" of similar welds. The value of destructive weld testing data is almost directly proportional to the possibility of the production of welds which are invariable in quality and soundness. The past decade in welding has been expended largely upon the development of welding methods to secure welds which are uniform in strength and quality. The strides of welding during this period are sufficient to announce the success of the study.

Today successful hand and machine welds are made and reproduced in astounding numbers. Welded structures are not uncommon, while in many applications welding has entirely replaced older methods of joining members.

The art of welding in many ways has outpaced testing methods—destructive test methods no longer satisfy the test needs of the welding engineer. New non-destructive tests for welded structures have been recently developed. Among these non-destructive testing methods are the stethoscope, the X-ray and the gamma emanation of radium, etc. Welds may now be tested for soundness without any physical destruction. These non-destructive testing methods give indication of being a worthy contribution toward the success of further welding projects since they indicate without destruction not only the presence of latent points of weakness in the weld but also the location of the weak areas.

Non-destructive testing methods have not, however, materially enshadowed the destructive testing method field. Physical properties of the weld metal and welded metal must be known. One of the more modern studies of welded sections has been fatigue investigation. Fatigue studies are valuable in the application of dynamic loadings upon a welded structure. There is available now a considerable amount of fatigue data upon welded sections. The conclusions from one[2] of these reports will be discussed in this paper.

Still more recent in origin and more deleterious in effect than fatigue in air is fatigue in the presence of a corroding medium, such as water, gases, etc. A wrought ferrous material with a fatigue limit of approximately 40% of its static tensile strength may have this fatigue limit lowered to 10% or even lower in the presence of a corrosive medium. Some study has been given to the corrosion-fatigue of metals but it is believed that this report upon the corrosion-fatigue study of welded sections is a pioneer and is one which, again it is believed, will be of interest to welding engineers in design work. Whether the presence of a welded section will affect the corrosion-fatigue life or limit of the steel is the problem of study in this research.

Equipment

The R. R. Moore rotating beam type fatigue machine was used in all of the tests. A few minor changes were made to the machine but only such as were necessary for the application of water to the specimen. A photograph of the machine is shown in Fig. 1. The speed of the machine was 1750 r.p.m.

The water used as a corroding medium was Bethlehem city tap water which is substantially a carbonate water. The water was applied directly upon the plane of maxi-

[1] Wilber E. Harvey, "Zinc as a Protective Coating against Corrosion-Fatigue of Steel," *Metals and Alloys*, 1, No. 10, April 1930.

[2] G. E. Thornton, "A Study of Welded Metals under Fatigue Tests," Journal of the American Welding Society, 9, No. 10.

mum stress which was in every case the location of the weld. A constant stream of water was applied and the temperature of the water was that of the surrounding atmosphere—about 70–80° F.

All the welded specimens were given a similar polish. The circumferential machining tool marks were removed by emery papers and the final finish was a longitudinal polish wherein no circumferential scratches from previous polishings were visible. It is more than possible that too much care was placed upon the polishing of the specimens. The surface finish for corrosion-fatigue work is probably not as important as the surface finish in ordinary fatigue work because the pits caused by the corroding agent are more severe than any very fine scratches in the surface. It was deemed wise, however, to eliminate any chance results of unproved theories.

$$c = {}^1/_2\, d$$
$$I = {}^1/_{64}\, \pi d^4$$
$$\frac{I}{c} = 0.0982\, d^3$$
$$S = \frac{\frac{W}{2}(L_1 - L_2)}{0.0982\, d^3}$$

For R. R. Moore Type Fatigue Machine with Standard 0.300-in. cross-section specimens

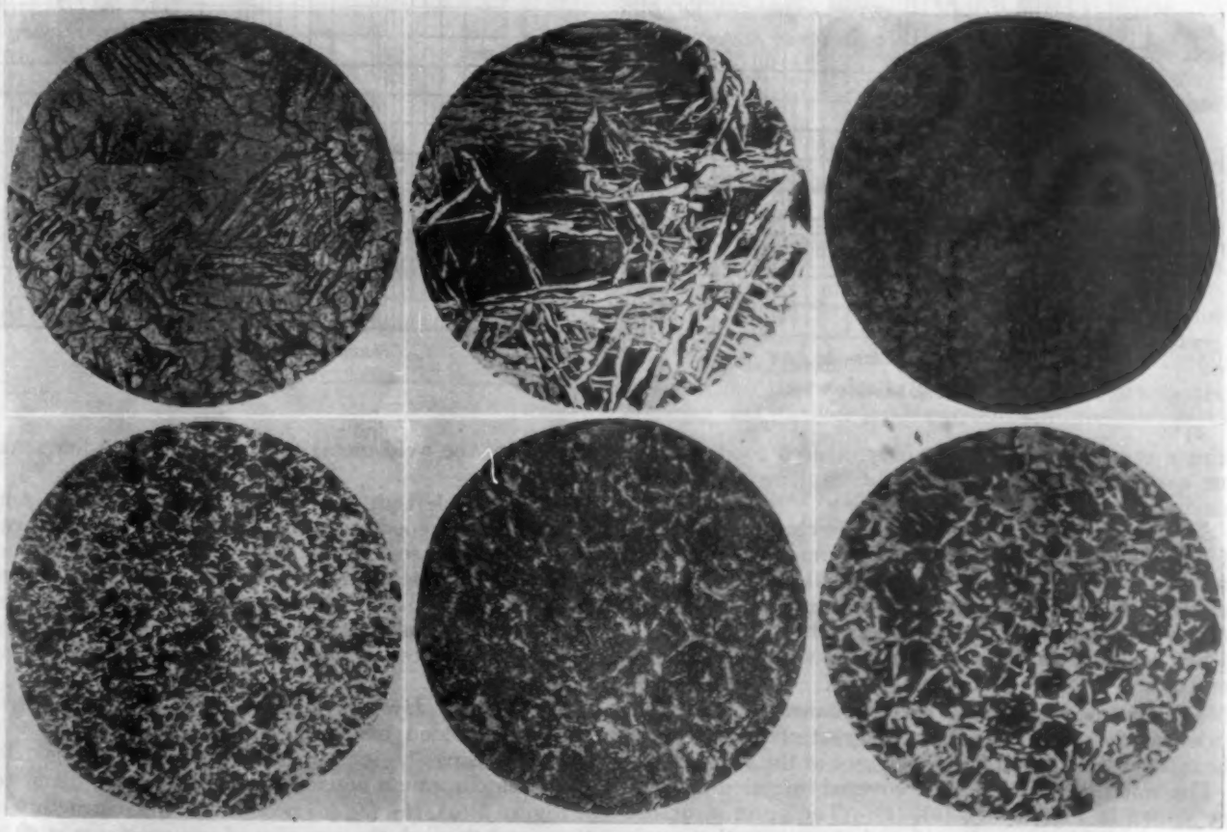
$$S = \frac{4W}{0.0053}$$
$$W = 0.001325\, S$$

Fig. 6—Gas Welds

Etchant—5% Nital

(a) Weld (b) Junction (c) Parent metal

Magnified 100 diameters



(a) Weld (b) Junction (c) Parent metal

Etchant—5% Nital

Magnified 100 diameters

Fig. 7—Electric Resistance—Flash Weld

Calculation of Weights and Stresses

A standard beam type specimen is used in this testing work. The beam is uniformly loaded at two points equidistant from the plane of maximum stress. The stresses formed are alternating flexures. A cross section of the weights and loading for this particular testing machine are shown in Fig. 2.

$$S = \frac{Mc}{I}$$

Material

Fire-box quality steel was chosen as the stock steel from which the fatigue specimens were to be made. The weld was to be in the critical section or the center of each specimen. In most cases two bars of plate were welded and specimens were cut from the welded bar, thus having a transverse weld at the critical section of the specimen.

Five types of welding were tested: (*a*) covered wire arc (*b*) bare-wire arc, (*c*) atomic hydrogen, (*d*) gas, (*e*) electric resistance—flash weld.

It was considered important to have the best welds possible and the cooperation of commercial welding

Fig. 8

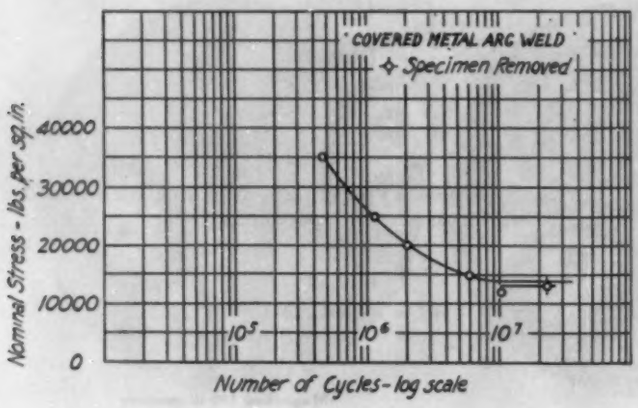
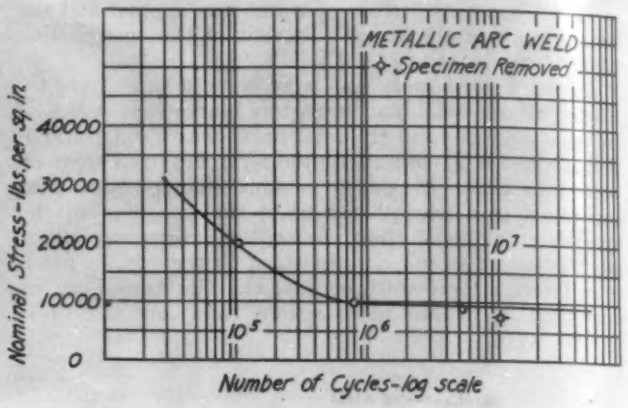


Fig. 9



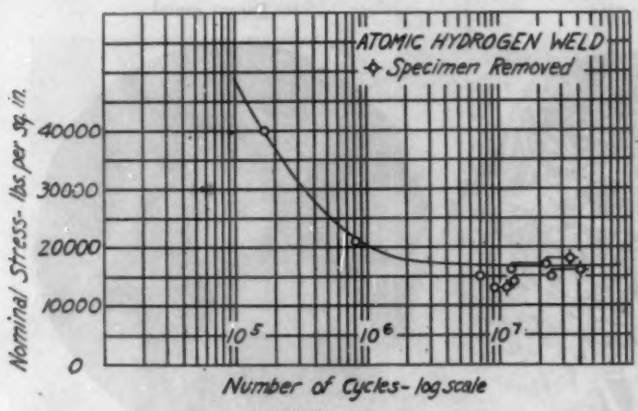


Fig. 10

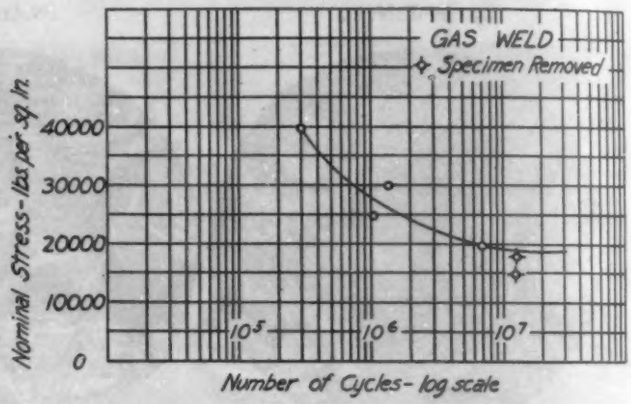


Fig. 11

firms was enlisted. This not only insured good welding but avoided the welding work being done entirely by one individual.

Since the slight variation possible in chemical analyses of fire-box steels would have little or no effect upon the corrosion-fatigue limit of the material, each company supplied its own plate for welding—in each case the carbon content being about 0.20% carbon.*

The welding information for the various types of welds is:

(*a*) *Covered Wire Arc Weld.*—The metal is deposited under conditions which gave the greatest protection to the molten weld metal from the gases of the atmosphere.

The microstructure of the covered metal arc welds are shown in Figs. 3 (*a*), (*b*), (*c*). The grain structure is typical of this type of weld and there is nothing new revealed in the micrographs. The grain size in the welded area is at least as small and as regular as in the parent metal, thus insuring strong physical properties.

(*b*) *Bare-Wire Arc Welds.*—The bare-wire arc welds were made by a local welder and were hand arc welds. Low-carbon steel was used as filler rod. The weld was a double Vee weld with a slight shoulder in the center of the bar.

Figure 4 (*a*), (*b*), (*c*) reveals the microstructure of these welded sections. The welds were very weak as will be shown by results later in the report. The shoulders were not properly heated and they formed a plane of weakness. This is shown in Fig. 16. The grain size in the deposited weld metal is small and it is believed that the fineness of the grain size is due to the shallowness of the depth of weld metal deposited—an immediate chilling of the weld metal occurring to give a fine structure.

It is possible that it is unfair to consider the results as typical of good arc welded specimens. However, time and expense limited further study at the present time. Again the results were published since it was kept in mind that the welding was done by an experienced, recommended welder using his own methods, and this paper contains results of commercially welded material.

(*c*) *Atomic Hydrogen Welds.*—The specimens were cut from welded bar. The welding was done with 70 amperes using $^1/_8$-in. tungsten electrodes. The filler wire was chromium-vanadium steel of $^1/_8$ in. diameter.

Figure 5 (*a*), (*b*), (*c*), (*d*) reveals the microstructure of the metal through the junction of one specimen into the weld. The oxide inclusion in the junction of this weld is very pronounced and is not typical of the junction found in other specimens examined. It was considered wise to show this poor junction since it reveals the effect of impurities upon the corrosion-fatigue strength of the weld. This specimen broke at a stress considerably lower than the corrosion-fatigue limit of the welded material. In the other specimens studied the junctions were sound. The weld metal grain structure is fine and appears strong.

(*d*) *Gas Welds.*—The oxyacetylene process was used with a neutral flame. The filler rod used was high test steel, the analysis of which is: C—0.18%, Mn—0.81%, P—0.008%, S—0.025%, Si—0.44%, Ni—0.13%, Cr—0.07%.

Sections were ground one-half way through the bar and the cavity closed with weld metal. Then the opposite side of the bar was ground half way and the cavity

* No chemical analyses were made but from the microscopic study the electric resistance welded steel seems considerably higher in carbon content.

Fig. 12

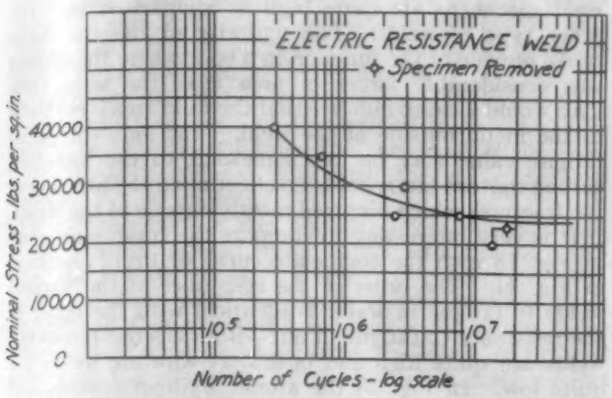
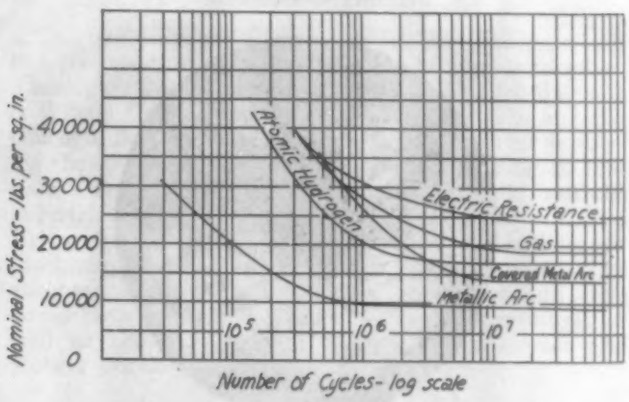


Fig. 13



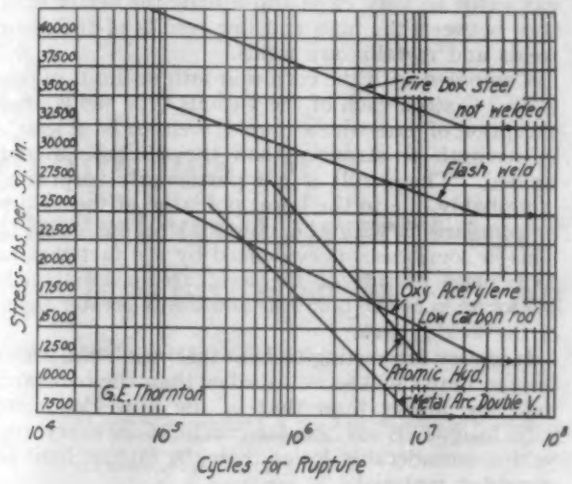


Fig. 14

filled with weld metal, giving a section of deposited weld metal in the critical section of each specimen.

Figure 6 (*a*), (*b*), (*c*) shows the microstructure of the gas welded specimens. The weld metal and adjacent metal show the Widmanstaetten structure which is characteristic of a cast metal.

(*e*) *Electric Resistance—Flash Welds.*—The electric resistance welds are of the flash weld variety. Fifteen kv-a power was used in welding for about two and one-half to three seconds per weld.

Figure 7 (*a*), (*b*), (*c*) is a characteristic micrograph of this type of weld. There is nothing unusual in the micrographs other than the carbon content seems considerably higher than that of fire-box quality steel. Correspondence identified the material as machine steel for bolts and screws. The lateness of the discovery made it impossible to test welds of lower carbon content steel.

Data and Results

The results of the tests are shown by graph in Figs. 8 to 12. From these curves may be chosen the following corrosion-fatigue limits: Covered wire arc welds, 14,000 lb. per sq. in.; bare-wire arc welds, 9000 lb. per sq. in.; atomic hydrogen welds, 17,000–18,000 lb. per sq. in.; gas welds, 19,000 lb. per sq. in.; electric resistance—flash welds, 24,000 lb. per sq. in.

To aid in evaluating the corrosion-fatigue values obtained for the welded fire-box steel specimens the following are fatigue and corrosion-fatigue values of fire-box steel of similar quality:

Pearlitic 0.20 C steel, fatigue limit (air)—25,000.[3]
Pearlitic 0.23 C steel, fatigue limit (air)—24,000.*
Pearlitic 0.26 C steel, fatigue limit (air)—25,000.[3]
Pearlitic 0.20 C steel, fatigue limit (water)—14,000.[3]
Pearlitic 0.26 C steel, fatigue limit (water)—17,000.[3]

For further comparative purposes—a portion of a composite curve[2] upon the fatigue (air) properties of various types of welded fire-box steel is shown. Only such portions of Prof. Thornton's study which are directly comparable to the work of this report are included in this composite curve.

[3] D. J. McAdam, Jr., "Fatigue and Corrosion-Fatigue of Metals," *International Congress for Testing Materials*, Amsterdam, September 1927.
* Author's laboratory.

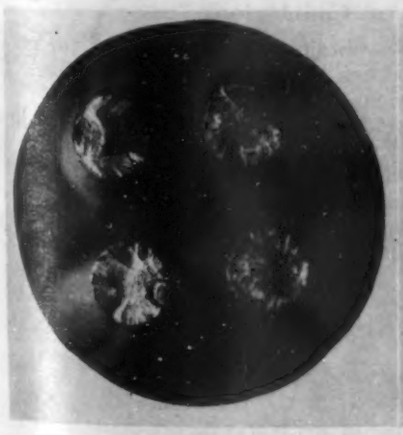


Fig. 15—Fractures of Covered Wire Arc Welded Specimen. Magnified 2 diameters

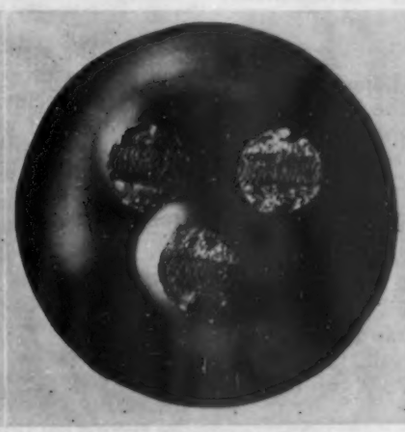


Fig. 16—Fractures of Bare-Wire Arc Welded Specimen. Magnified 2 diameters

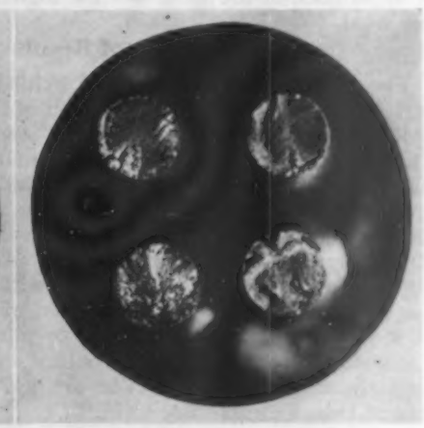
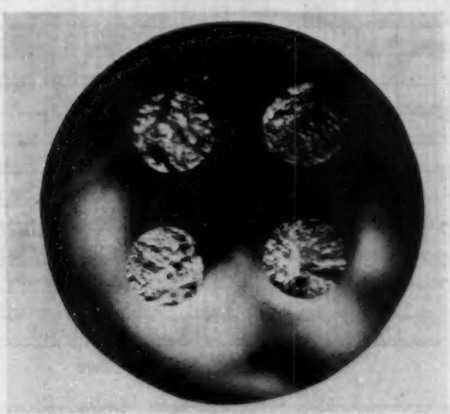


Fig. 17—Fractures of Atomic Hydrogen Welded Specimen. Magnified 2 diameters

Fig. 18—Fractures of Gas Welded Specimen. Magnified 2 diameters



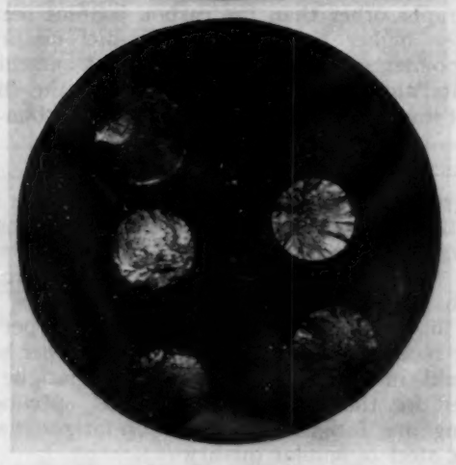


Fig. 19—Fractures of Electric Resistance—Flash Welded Specimen. Magnified 2 diameters

The fractures of the corrosion-fatigue specimens are shown in Figs. 15 to 19.

The electric resistance welded specimens in most cases broke outside of the weld. All of the metallic arc welds fractured directly in the weld. In the atomic hydrogen, gas and covered wire arc welds the breaks occurred in various places—at times in the welds and other times outside the weld. In general, in the atomic hydrogen and fusion pressure welds at higher stresses specimens broke outside the weld while the specimens at lower stresses broke within the weld. In the gas welds this condition was reversed—the lower stresses broke outside of the weld and the higher stresses within the weld.

Discussion of Results

The fractures of each type of welded specimen were perfectly normal with the exception of the bare-wire arc welds. The arc welder used his own discretion in choosing the type weld and an examination reveals that the shoulders of the double Vee weld had never been properly closed. It is very probable that the lack of sound cross section caused the very low corrosion-fatigue limit of 9000 lb. per sq. in. However, the low results obtained check very closely with the low double Vee arc weld fatigue results obtained by Prof. Thornton as shown in Fig. 14. It is very probable that a single Vee weld would have given a better result, since it has been shown that a single Vee arc weld is stronger in fatigue than a double Vee weld.[4]

[4] Charles H. Jennings, "Fatigue and Impact Tests for Welds," JOURNAL OF THE AMERICAN WELDING SOCIETY, 9, No. 9.

The results obtained with the electric resistance flash weld specimens are quite high in comparison with the other type of welds. The majority of the specimens broke outside of the junction in a spot where the section was considerably larger in area than the weld area. This would seem to indicate that the weld area is cathodic to the metal outside of the weld. The high corrosion-fatigue value may be due somewhat to the increased carbon content but it holds no effect upon the location of the fractures which occurred mostly outside of the welds.

It is very interesting to compare the composite curve in Fig. 13 with the composite curve of Prof. Thornton in Fig. 14. The order of the resistance of the various welds to fatigue in water is identical with the order of the resistance to fatigue in air. Both electric resistance welds are quite high and both bare-wire arc welds are quite low. In Fig. 13 the atomic hydrogen welds and gas welds lie very close and a little bit better than half way between the high and low results of the resistance welds and metallic arc welds.

Compared with the corrosion-fatigue limits of pearlitic 0.20% C steel, each of the various type welds, with the exception of bare-wire arc weld, seem to be at least equal in strength or stronger than the similar material unwelded. This result is not particularly surprising. It is probably due to the lower potential of the weld metal in comparison with the potential of the stock metal. This in some cases is evidenced by the fact that failure took place outside of the weld area even though the section area at the point of failure was greater than that of the welded area.

It is very interesting to note that, while the corrosion-fatigue limits of the welds other than the bare-wire arc weld are higher than that of the unwelded material, with fatigue in air the fatigue limit in every type of weld is considerably lower than the fatigue limit of the unwelded material.

Thus, it would appear as if the effect of welding upon the corrosion-fatigue limit of the material is relatively slight as compared with the marked decrease in fatigue limits of steel after welding.

There does not appear to be a correlation between grain size and corrosion-fatigue limit. This, however, again is to be expected since corrosion-fatigue is more nearly an electrochemical phenomenon than anything else.

The presence of the oxides revealed in Fig. 5 (*d*) gave a failure for this particular specimen stresses at 13,000 lb. per sq. in. after 9,000,000 cycles while the corrosion-fatigue limit of the atomic hydrogen welded specimen was about 17,500 lb. per sq. in.

Conclusions

From the results obtained in this study of the corrosion-fatigue properties of welded low-carbon steel, the following conclusions may be made:

The effect of welding upon the corrosion-fatigue limit of a low-carbon steel is not deleterious except in the case of the bare-wire arc welded specimens. It is possible that the corrosion-fatigue limit of the arc welded specimens might be higher with a better quality weld. This conclusion is in direct contrast with the results obtained in the fatigue in air studies of similar welded material where in all cases the fatigue limit of the unwelded material was very considerably lowered with the presence of a weld.

In every type of weld, with the exception of the electric resistance-flash weld, the corrosion-fatigue limit of the respective types of welds was higher than the fatigue limit in air. The fatigue limit in air of the electric resis-

tance-flash welded specimens was very slightly higher than the corrosion-fatigue limit. These facts are surprising but not to be unexpected since in many cases the parent metal is anodic to the weld metal.

Grain size does not seem to have any effect upon the corrosion-fatigue limit of the welded materials. This fact is to be expected since the corrosion-fatigue limit seems to be correlated only with the electrochemical properties of the material.

Impurities such as slag particles lower the resistance of the welded material to the combined action of corrosion and fatigue stresses.

It is realized that this paper is only pioneer in its efforts and that there still remains much study to be done. It is hoped that perhaps this early report will stimulate the efforts of others toward a more perfect solution of the problem.

Acknowledgments

The cooperation of the various companies which did the welding work for this study was invaluable. Thanks are due to the General Electric Co., the Babcock & Wilcox Co., the Swift Electric Welder Co. and the Chicago, Burlington and Quincy Railway Co. for supplying the specimens. It is particularly gratifying to find such a strong link between the scientific field and the industrial field. The Grant-In-Aid of the National Research Council for its financial aid which defrayed machining and polishing expenses in many cases. The encouragement of Profs. Bradley Stoughton and Inge Lyse, both of Lehigh University, was appreciated, as well as the assistance of Messrs. Cares Keyser and Robert Vogel.

Advantages of Thyratron Control for Resistance Welding

By **WARREN C. HUTCHINS**

✦Paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 6, 1932. Mr. Hutchins is connected with the Industrial Department of the General Electric Co.

THYRATRON control for resistance welding. This phrase reduced to its most simple expression is: a device for closing and opening an electrical circuit which determines the time power is applied to a resistance welder. Before going into any detail regarding this device, it is desirable that we all understand the reasons for developing the Thyratron control. A brief review of resistance welding in its early stages and a discussion of the resistance welding developments will clearly familiarize us with the necessary fundamentals.

During 1886, the first patents covering resistance welding of butted stock by A.C. or D.C. current were issued to Prof. Elihu Thomson. One piece of stock was clamped in each side of a machine and pressed together. Current was passed through this joint, the resistance of which generated sufficient heat to bring the surfaces to a plastic state. Additional pressure was then applied to force the parts together, causing the surfaces to weld.

During the following years, machines were developed for welding of wire, chain links, seams in thin metal shapes, pipes end to end, cross wire fabric, and for making spot and projection welds.

All of these processes involved crude, cumbersome machinery, which was slow in operation. The welding circuit was closed manually and current allowed to pass. The circuit was manually opened when, in the opinion of the operator, the metal was sufficiently hot to make a satisfactory weld. These methods met the requirements of industry for ten years or more.

Early welding difficulties did not include problems of controlling the welding time for two main reasons:

First, the work commonly welded was mild steel, probably the easiest of all metals to weld. The main reason being: it is plastic over a wide temperature range, obviously eliminating the need for accurate control of the heat. It is interesting to note that welding of copper was probably the earliest commercial application of the resistance welding process.

Secondly, the machines were of such capacities as to make it necessary to use long welding times. This was because high speed production had not become a major factor in the business world, and high speed welding would have demanded greater momentary surges of single phase power at a low power factor. Generating or line capacity was not usually available for such an increased demand. This problem could have easily been overcome, however, had a motor-generator set with flywheel been applied.

With the development of the automobile and other high speed production requirements, and the introduction of metals which required more accurate measurement of the heat applied, came welders of greatly increased capacities and problems of accurate time control.

It was learned that resistance welding depended upon the pressure between the surfaces to be welded, the duration and value of the current, resistance of metal, etc. The heat generated is in proportion to the product of the current squared, the duration of current application and the resistance of the joint.

Let us consider line welding of sheet metal, the double thickness being passed between two rolls at a constant speed. By proper adjustment of voltage applied to the rolls, the resulting current which passes through the two sheets will weld them together producing a "line weld." In this method of welding, factors other than the accurate control of heat must be considered.

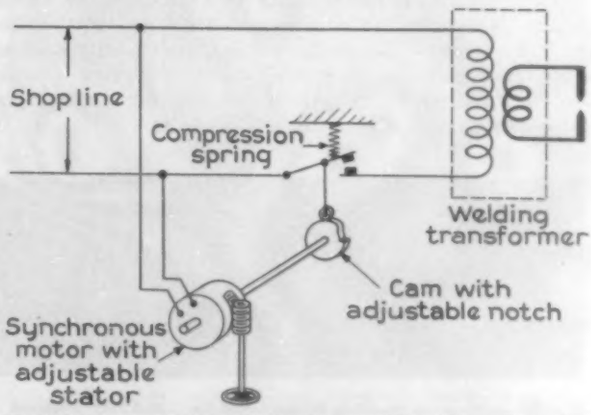


Fig. 1—Resistance Welder with Synchronous Motor Driven Contactors.

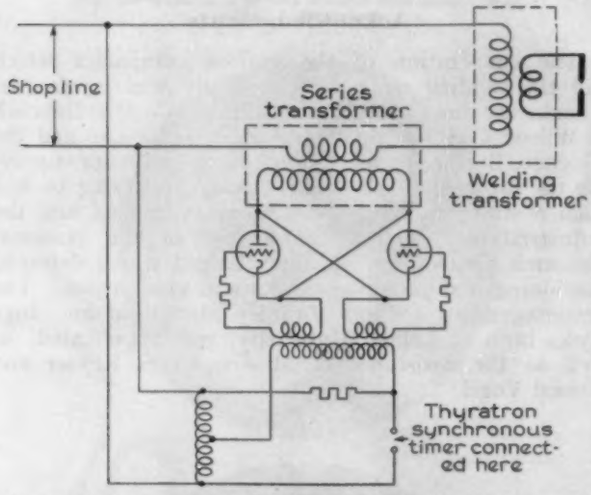


Fig. 2—Resistance Welder with Thyratron Control Showing Arrangement of Series Transformer and Control Circuit. The Thyratron synchronous timer circuit is not shown

Assuming the power is constantly applied, the parts being welded will require a relatively large amount of heat at the start of the weld. As progress is made, the heat will travel ahead of the point of contact and less heat will be required. Also, if the heat is set for the thickest part of the plate, the thinnest part may be burned. Also the current will follow the path of least resistance, and instead of making a continuous weld it may skip certain spots giving an imperfect weld.

To overcome these objectionable features, an interrupter is used in series with the welder transformer primary—a device for making and breaking the electrical circuit. The line weld then becomes a series of overlapping spot welds, allowing the metal to chill between each spot and preventing the building up of heat ahead of the rolls. The current is forced through the joint by practically instantaneous high voltage which is sufficient to break down the path between the parts being welded. With this process, a line weld can be started and completed, welding both the thin and heavier sections, with one heat setting.

The outstanding advantage gained by this device is increased speed of welding. The duration of current for each spot being very short and, in view of the metal being allowed to chill between each spot weld, the current can be increased many times beyond the value of current for uninterrupted line welding.

Spot welding is similar to line welding except that a point contact is used instead of rolls, and only one spot weld is made after each set-up.

Considering only line welding for a few minutes, visualize the necessary contactors or control for interrupting the line current. To attain welding speeds approaching those required today by industry, it is necessary to make several hundred interruptions per minute. The range of capacity usually being from 25 kv-a up to 100 or 200 kv-a. To do this mechanically is difficult but not entirely impossible. Satisfactory results have been obtained up to 300 interruptions per minute or more provided the rate of power input to the welder did not greatly exceed 25 kv-a. Naturally, the making and breaking of contacts several hundred times per minute means wear and pitting of contacts. For large power input rates, it has been practically impossible to prevent occasional arcing over as the contacts are opened. This arcing over results in an imperfect weld and renders the contactor useless until the tips have been replaced or repaired, and readjustments made. This type of contactor control is often submerged in water and repair means expensive non-productive delay besides the labor cost. There is one large automobile manufacturer who found that during normal operation, the contactors for his line welder had to be repaired once every eight hours to insure reasonable satisfaction. This does not represent an unusual condition, but is typical of a great many installations today.

High speed line welding has now reached a stage where the duration of each "on" period is only a few cycles. Assume a job where best results are obtained when the current is on for only three cycles. Should the contactors allow just one extra cycle to pass, or due to wear of the contacts the passage of current was only for two cycles, the heat applied to the weld would be respectively $33\frac{1}{3}\%$ greater or less than the requirement for best results. This would probably mean either a burnt spot or, in the case of too short a time, the weld would not be complete. Even for the smaller capacities, it is very difficult if not impossible to get exact duplication of "on" periods over an appreciable length of time without frequent adjustments.

Two main problems are, therefore, presented to control engineers: first, to furnish a control which will stand up continuously without need of frequent repairs or adjustment; and second, to furnish a control which will positively close the welding circuit, measure out a definite number of cycles and then open the circuit, measure out another period for the open circuit condition, then again close the circuit, repeating this cycle of operation until it is desirable to make a change in the welding cycle.

These problems have been solved by our engineers by properly applying tube type mercury-vapor grid controlled rectifiers, known as the Thyratron tubes.

The Thyratron tube has three major elements: namely, the anode, cathode and grid. All three are within the tube which is filled with mercury vapor or some inert gas. The Thyratron tube is used for conducting current but does so only when a sufficient positive anode voltage is applied to cause ionization of the mercury vapor.

Picture the tube with the anode and cathode an inch or so apart with the grid between. In speaking of voltages of the Thyratron tube consider the cathode as a reference point. Provided the grid is held sufficiently negative, a relatively high positive voltage can be ap-

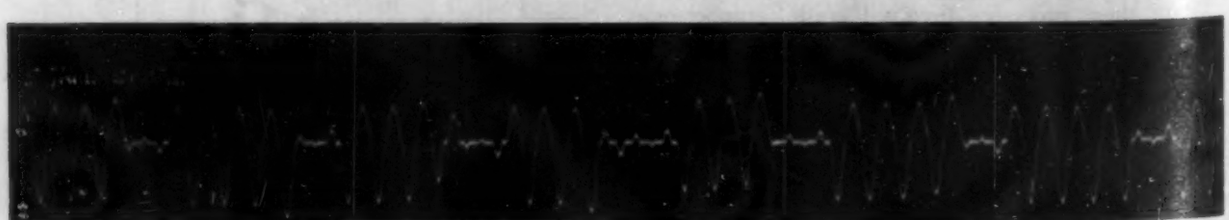


Fig. 3—Oscillogram Showing Variations of "on" and "off" Periods. Power is applied to line welder when motor driven contactors control the grid circuit of the Thyratron control tubes

Fig. 4—Oscillograms Illustrating Range of Control to Be Obtained with Thyratron-Tube Control for Resistance Welding Machines. *A*—2 Cycles on, 1 Cycle off. *B*—1 Cycle on, 2 Cycles off. *C*—3 Cycles on, 2 Cycles off. *D*—4 Cycles on, 1 Cycle off. *E*—9 Cycles on, 19 Cycles off. *F*—13 Cycles on, 2 Cycles off. *G*—97 Cycles on, 7 Cycles off

plied between the anode and cathode without conduction of current. While this high anode voltage is applied, the grid voltage may be increased positively. At a certain critical grid voltage, the mercury vapor will ionize and current will flow between the anode and cathode. The grid voltage at which ionization takes place is called the critical voltage of the Thyratron tube.

Therefore, by properly controlling the grid voltage, the tube can be made to begin passing current at a predetermined instant.

The grid cannot stop the flow of current, but if the current ceases to flow long enough for de-ionization to occur, the grid can regain control and prevent the current starting again. If an A.C. voltage is supplied to the anode and cathode, the grid has an opportunity of regaining control once each cycle, and can delay the start of the current flow for as long a period as the grid is sufficiently negative with respect to the cathode.

Let us consider a line welder where the current is rapidly interrupted, as the work is welded, by mechanically timed contactors connected in series with the welder transformer primary. (See Fig. 1.) This type of control usually consists of a synchronous motor with adjustable stator, driving a notch type cam, directly or through a set of gears. A plunger follows the contour of the cam and closes and opens the contactors once every revolution of the cam. The contactors can be made to open when the line voltage is approximately zero by adjusting the stator of the synchronous motor. As stated previously, however, it is practically impossible to prevent occasional arcing at the contactor tips, and despite very careful adjustments being made, the closing and opening of the contacts will probably not occur at the same relative point on the voltage wave of each welding cycle. The result is unbalanced head and a sacrifice of weld quality.

Where Thyratron control is used, a series transformer wound for line voltage and frequency takes the place of the mechanical interrupter. (See Fig. 2.) Connected across the high voltage secondary of this series transformer are two Thyratron tubes so arranged that one passes half of each cycle and the other Thyratron tube passes the other half of each cycle when the grid voltage is sufficiently positive.

When the Thyratron tubes are not passing current, the transformer represents a very high reactance in series with the primary of the welder transformer across which practically the full line voltage drop occurs. When the tubes are passing current, the secondary of the series transformer is literally short circuited, decreasing the reactance of the series transformer to practically zero. Thus, the series transformer becomes a very good conductor impressing practically full line voltage across the terminals of the welder. It is, therefore, apparent that by properly controlling the grid voltage of each tube, it is possible to control the duration of the "on" period for welding to any exact number of cycles, and likewise the "off" period can be controlled to a desired number of cycles. Two large Thyratron tubes are used for short circuiting the secondary of the transformer. Three small tubes in an auxiliary circuit including a group of reactors, resistors and capacitors control the grids of the large tubes in such a manner as to produce the desired results. This auxiliary circuit is named the Thyratron synchronous timer.

The details of the Thyratron synchronous timer circuit are too much involved to warrant taking the time to explain them. Anyone who is interested further, however, may refer to an article titled, "Thyratron Control for Resistance Welding Machines" published in WELDING, Part I in May and Part II in June of this year.

Before this Thyratron timer was adopted, attempts were made to utilize mechanical devices already available which would properly control the grid circuits of the

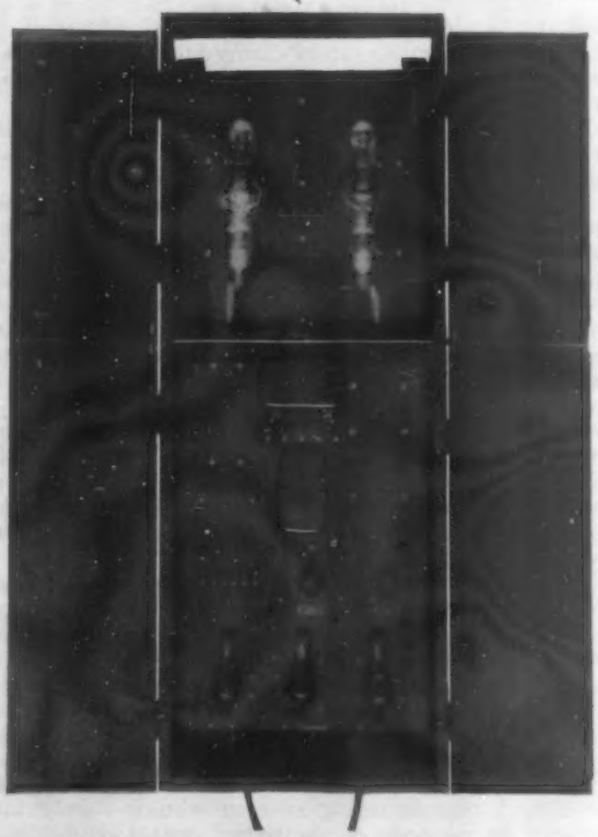


Fig. 5—Thyratron Welding Control Panel with Synchronous Tube Timer, 220/440/550-Volt, 60-Cycle Power Supply. Used with series transformer to control line welding transformer

Thyratrons and be sufficiently flexible to permit the desirable changes in the welding cycle such as ratio of "on" to "off" period, and variation of total time for "on" period plus "off" period. Oscillogram (Fig. 3) shows the typical results. Variations up to one complete cycle are apparent in the duration of the "on" period. Oscillograms *A* through *G* in Fig. 4 show some of the many settings practical with the Thyratron control. Figure 5 shows photograph of a typical installation of Thyratron control to line welding.

Range of Operation

The Thyratron control equipment will operate satisfactorily up to 1800 interruptions per minute on 60-cycle power supply. This means that the "on" period and "off" period include only one cycle each. By simple adjustments of snap switches and variable resistance dials

Fig. 6—Milk Can Being Line-Welded on Machine Operated with Thyratron Tube Control

the speed of operation can be changed to give any number of cycles up to 40 or more for the "on" period and an equal or different number for the "off" period. Figure 6 shows a Thyratron control panel for line welding with the enclosing case doors open. Note the snap switches and dials used in making proper setting of the control.

By using higher frequency, say, for instance, 120 cycles, it is possible by welding with one cycle to get the equivalent of only $^1/_2$ cycle of the 60-cycle supply. Or, it is possible on this higher frequency to get a maximum of 3600 interruptions per minute, each impulse having a duration of $^1/_{120}$th of a second. Should 240 cycles be used, a maximum of 7200 interruptions per minute are practical. One cycle is equivalent to $^1/_{240}$th of a second.

There is practically no limit to the capacities which can be handled satisfactorily with the Thyratron control. Standard apparatus is now available for controlling welders up to 350 kv-a. The control can be made suitable for loads up to 700 kv-a for an increased cost which is small compared with the increased capacity.

The Thyratron control for spot and projection welding is very similar to the line welding control. It allows only one impulse of power to pass for making one spot, shuts off, and the circuit cannot be reclosed until the electrodes have been lifted from and again clamped on the work. It is possible to weld with a duration of any desired number of cycles depending upon the setting of the control.

Recently, we received a letter from an engineer of a prominent manufacturing concern who is deeply interested in methods of controlling resistance welding circuits. In reference to Thyratron control for resistance welding, he wrote the following words:

"Hence we have passed from manual control, through mechanical control, through mechano-electrical control, to the ideal pure electrical control of power input."

Up to this time, I have discussed welding without putting any emphasis on the kind of metal to be welded. One might think this excellent control is not necessary, in that for years satisfactory welding has been accomplished without the very close time adjustment. True as this statement may be, the Thyratron control is often justified even for welding of mild steel, in that much greater speeds can be obtained, thus cutting down on labor, floor space and number of machines necessary to do the same job, besides producing a better and more consistent resulting weld.

Let us consider a metal which is more difficult to weld than mild steel. For instance, tern plate—a mild steel dipped in lead. This material is being used widely for automobile gasoline tanks. For approximately two years efforts were made by a certain automobile manufacturer to determine the best device which would produce satisfactory line welds on this metal at an economically high speed. The final decision was to install a large number of Thyratron panels to control welders in the production of these automobile gasoline tanks. A decided increase in speed was obtained with a high per cent increase in acceptable tanks.

Probably the most talked of metal today is "stainless steel," or chrome-nickel-steel. Often it is called 18–8, which represents the percentage of chromium and nickel, respectively.

Some of its characteristics are:

1. Corrosion resisting.
2. Physical properties excellent (150,000 to 200,000 lb. per sq. in. in ultimate tensile strength).
3. Electrical resistance 7 to 12 times that of ordinary steel.
4. Does not respond to a magnet.
5. It is softened by quenching from approximately 2000° F.
6. If the temperature is raised to 1400° or 1500° F. for a few tenths of a second, a radical change takes place in the structure of the steel. Carbides precipitate, and the iron, chromium, nickel and carbon become a mixture. It loses its resistance to corrosion and responds to magnetic action after cooling.
7. All the desirable characteristics can be reinstated by heating to approximately 2000° F. and quenching.

Probably the most surprising characteristic of this metal is the fact that to soften or anneal it, it should be quenched. In other words, time is an important factor in annealing to maintain the desirable characteristics of the metal. If the metal is quickly heated to the temperature at which carbides precipitate readily (say, 1400° to 1500° F.) and is quickly cooled, all in a sufficiently short time, the desirable physical properties of the metal are maintained.

Consider spot welding of stainless steel. If it is welded on the usual type of welder in one-fifth of a second or more, the metal at the point of fusion probably reaches 2500° F. In all directions from the weld, there is a zone which reaches only the critical temperature at which the carbides precipitate and the various metals separate to form a mixture with the carbon.

Now let us assume that this welding is done in $^1/_{60}$th of a second instead of $^1/_5$th of a second. The weld will be completed and the heat dissipated throughout the major portion of the plate before the carbides have had time to form and before the homogeneous structure can become a mixture.

Welding of stainless steel is being done every day by Thyratron control in both production and experimental shops without discoloration on the surface of the pieces being welded. Only a few weeks ago, I saw a great number of beautiful welds made on the high tensile strength stainless steels in various thicknesses from 30 mils down to 10 mils. This was done without the slightest trace of discoloration. These samples could be pulled to find that always a hole would be pulled in one plate or the other. Another test to which we subjected samples was twisting the weld through an angle until failure occurred. This angle always exceeded 90°.

As another example, it is a known fact that Dow metal, a magnesium alloy, can be spot welded, but it is often thought to be impossible to get consistently good results. It is our confirmed opinion that the application of Thyratron control is an important factor in solving this problem.

An installation of the Thyratron control equipment has been made at the plant of George D. Ellis & Sons, Inc., of Philadelphia (see Fig. 5), in connection with the manufacture of oil cans. The side, top and bottom seams are welded by intermittent line welding. Very satisfactory results have been obtained, the Ellis Company reporting that it is consistently obtaining much better and more uniform welds than they have been able to secure through the use of a number of different types of mechanical interrupter.

One might ramble on at length about the various applications and advantages derived by controlling resistance welding machine circuits with the Thyratron tube control.

As a summary, I would like to repeat the outstanding advantages of the Thyratron control for resistance welding machines:

1. Flexibility—permitting adjustment to the most desirable welding condition by simply adjusting snap switches and dials on the panel.
2. Exact duplication. After the most desirable condition has been established. The Thyratron control will duplicate the duration of "on" period until it is desired to make a change in the welding cycle.
3. There are no moving parts to necessitate adjustment, replacement and general maintenance.
4. The Thyratron control is completely protected by a steel enclosing case, making it absolutely suitable for industrial application. In other words, it is not frail.
5. There is practically no limit to the capacity which can be satisfactorily controlled. The Thyratron control is suitable for the smallest welding machine up to 700 kv-a and greater.
6. The Thyratron control functions without noise.
7. Elimination of contactors, water-cooled or otherwise.
8. Above all the Thyratron control is rugged and dependable, the tubes having an average expected life of 10,000 hours or the equivalent of more than 365 days operating 24 hours a day.

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Distribution of Stresses in Welded Double Butt-Strap Joints

By S. C. HOLLISTER *and* A. S. GELMAN

†This paper was presented at the Fall Meeting of the American Welding Society, in Buffalo, Oct. 4, 1932. Prof. Hollister is Professor of Structural Engineering, Purdue University, and Prof. Gelman is Research Assistant, Engineering Experiment Station, Purdue University. Report rendered to the Fundamental Research Committee of the American Bureau of Welding.

Introduction

DURING the past ten years welding has been applied to all branches of structural work. From a purely experimental stage it has gradually developed into one of the every-day tools of a structural engineer. The amount of work done and the importance of structures on which welding has been used justify a thorough study of the stress distribution in welds as well as the analysis of welded connections.

A great deal of experimental work has been carried out by various investigators in an effort to secure the data necessary for the rational design of welded structures. With few exceptions, these tests were confined to the determination of the ultimate strength of a weld or a welded joint. The results thus obtained helped to improve both the quality of materials used in welding and the technique of the process. Furthermore, the ultimate strength of a weld furnished a basis for the design of welded connections. Tests which disclose the behavior of a particular form of attachment by welding are yet to be made. Tests determining ultimate strength give the basis for judging ultimate carrying capacity of a simple joint. They also disclose the presence, if any, of undesirable metallurgical results of welding. In this way a structural engineer has available ample assurance of reliable safety of given simple types of connections. He still lacks information which would permit him to design with a detailed knowledge of stress transfer.

In many cases a structure possessing adequate ultimate strength will be thoroughly satisfactory and will perform safely over a long period of time, while in other cases the sole consideration of the ultimate strength is insufficient to insure such service. This is particularly true of structures or machine parts subjected to repetitive loads when fatigue stresses may occur before the yield point is reached and the failure will result with no apparent effect of the ductility of metal. Stresses of this nature are based on the elastic distribution of stresses and are affected by high local concentrations. It is not suggested here that a structure should be designed on the basis of local stresses. However, it is very desirable to avoid excessive stress concentrations in any part of the structure. The knowledge of the distribution of stresses in various types of welded connections will help to select the proper detail for each particular case.

Fig. 1—Forms of Butt-Strap Connections Tested

A considerable number of tests have been made to study the fatigue properties of the metal deposited in the welding operation. Such studies are necessary to determine possible undesirable physical results of the fusion. Such specimens are not intended to disclose the efficiency of a given type of connection under fatigue conditions. Welding literature contains no information of direct tests of progressive fatigue failure which might result from an unequal distribution of stress arising from the type of connection made in the specimen.

The elimination of high local stresses where fatigue-producing loads are present is particularly important in welded connections as the data now available[1,2,3] indicate rather low endurance limits for both butt and fillet welds. Moreover, these limits are based upon tests made on small welded pipes and their applicability to long welds used in structural work is questionable. No information on endurance limits of side welds was found in the literature. Generally speaking, a weld possessing uniform stress distribution is expected to show higher resistance to fatigue stresses.

The study reported here was undertaken to determine the elastic distribution of stresses in various types of butt-strap joints. A very interesting study of the stress distribution in the welds of side-welded joints was reported to the AMERICAN WELDING SOCIETY by J. Hammond Smith[4] and also by W. H. Weiskopf and Milton Male.[5] Their experimental results checked the values for stresses in side welds determined by means of a theoretical formula. Similar stresses were determined for side welds in the series of tests reported here; however the method of approach was different. In addition to joints formed by side welds only, diamond-shape straps and rectangular straps welded along four sides were tested.

The authors are indebted to C. J. Geiger, graduate student, and A. Zimmerman, senior, of the School of Civil Engineering, Purdue University, for their assistance in obtaining and reducing data reported here.

Forms of Joints Tested

Since under elastic stress the side welded splice plate has been shown to give a very irregular stress distribution, and since this form of splice plate is at the present time in common use, the present series of tests was laid out to compare other forms of splice plates to this one in an effort to identify that form of splice plate which would give the most satisfactory stress distribution.

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[3] Morris Stone and J. G. Ritter, "Electrically Welded Structures under Dynamic Loads," JOURNAL OF THE AMERICAN WELDING SOCIETY, March 1930.

[4] J. Hammond Smith, "Stress-Strain Characteristics of Welded Joints," JOURNAL OF THE AMERICAN WELDING SOCIETY, Sept. 1929.

[5] W. H. Weiskopf and Milton Male, "Stress Distribution in Side Welded Joints," JOURNAL OF THE AMERICAN WELDING SOCIETY, Sept. 1930.

The types of splices chosen are shown in the accompanying photograph (Fig. 1).

Optical Study of Joints

Before the full-sized steel specimens were made, celluloid models of proposed joints were prepared and studied in polarized light.[6] The stress-flow lines for the main plates of these splices are shown in Figs. 2 to 5. These lines indicate the direction of principal stresses at each point. Converging lines correspond to an increased intensity of stresses. From the inspection of Fig. 2 it is apparent that a stress concentration exists near the end of the weld. A similar condition is present in Fig. 3. However, the "crowding" of stress lines in the second case is considerably less pronounced than in the first, and shows a much more uniform distribution of stresses across the plate. A very non-uniform distribution of stresses along the weld is found in Fig. 4. Very little stress reaches the outside corner of the weld. To correct this condition the actual splice specimen was made with the inclination of weld of about 30 deg. and the length of side welds was reduced. Figure 5 shows very good distribution of stresses in the main plate of a diamond-shaped weld. In all these members the direction of principal stresses at any point approached vertical position and, consequently, the measurement of strains in vertical direction (parallel to the line of pull) gave the maximum deformations. The only case when the slope of the direction line is appreciable is found in Fig. 4. As the steel specimen of that type was modified the actual direction of stress lines follows that of the lines for the diamond-shaped joint and is close to a vertical.

A study of stress flow through fillet welds of different forms was made by means of polarized light at Purdue University and was reported by Professor S. C. Hollister.[7] The direction lines for a double butt-strap joint are shown in Fig. 6. A high concentration of stress exists

Fig. 2—Lines of Principal Stress in Main Plate of Model of Specimen 1 Determined Photo-Elastically

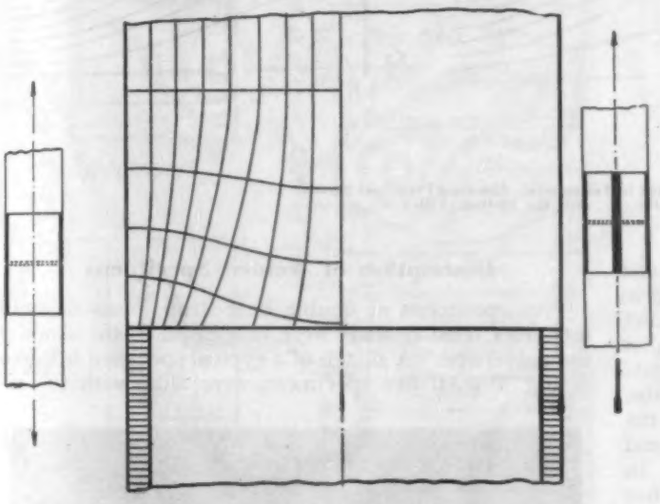


Fig. 3—Lines of Principal Stress in Main Plate of Model of Specimen 2 Determined Photo-Elastically

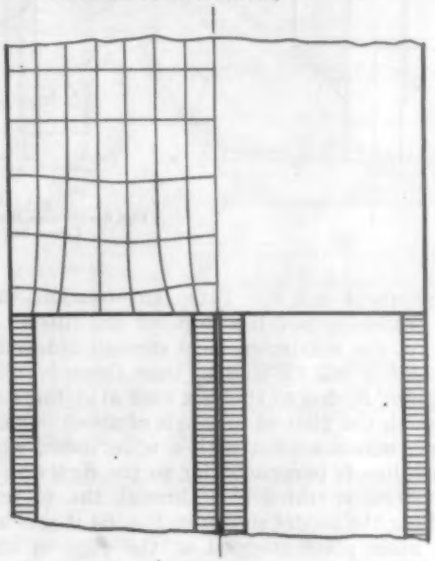


Fig. 4—Lines of Principal Stress in Main Plate of Model of Specimen 4 Determined Photo-Elastically

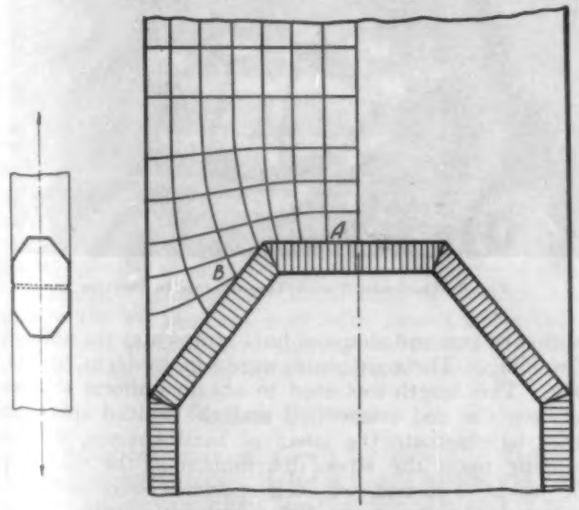
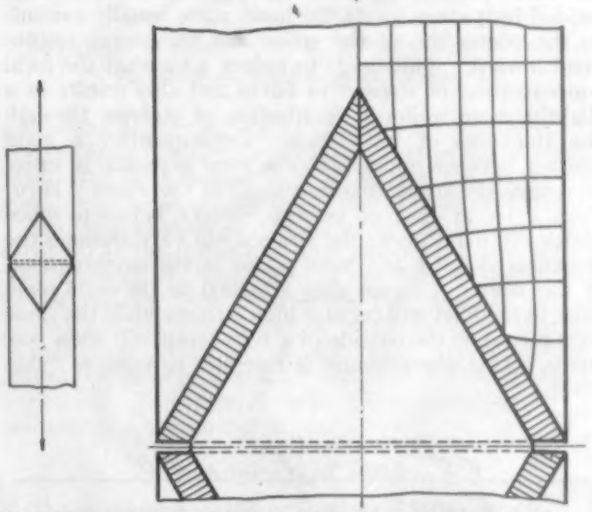


Fig. 5—Lines of Principal Stress in Main Plate of Model of Specimen 5 Determined Photo-Elastically



[6] For further details of the optical method, readers are referred to Coker, *Gen. Elec. Rev.*, 1920, 1921; Baud, *Proc. Engrs. Soc. W. Pa.*, 1928; Hollister, *Proc. West. Soc. Engrs.*, 1932. See also Coker and Filon, "Treatise on Photo-elasticity," Cambridge, 1931, for theories involved.

[7] S. C. Hollister, "Stress Distribution in Transverse Fillet Welds," *Jour. West. Soc. Engrs.*, 1932.

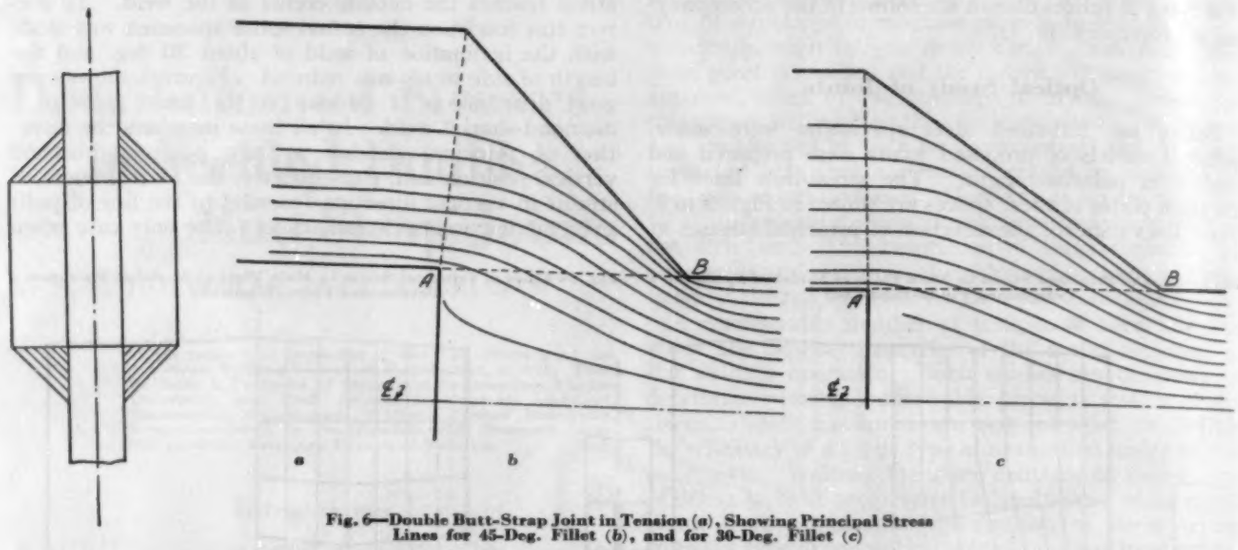


Fig. 6—Double Butt-Strap Joint in Tension (*a*), Showing Principal Stress Lines for 45-Deg. Fillet (*b*), and for 30-Deg. Fillet (*c*)

at points *A* and *B*. This concentration can be reduced by flattening out the slope of the fillet. Referring to Fig. 4, the maximum local stresses induced in the fillet a point *A* will be smaller than those found in the fillet at point *B*, due to the fact that at *A* the stress line cuts through the fillet at an angle of about 60 deg. and, thus, works across a fillet with a wider base, while at *B* the stress line is perpendicular to the direction of weld and the stress is transferred through the 45-deg. fillet. In making the model shown in Fig. 6*a* it was assumed that the main plate stopped at the edge of the fillet. In welded butt-strap joints the main plate usually extends to the center-line of the splice and the straps cannot bend inward. This tends to reduce somewhat the local concentration of stresses in fillets and also results in a slightly more uniform distribution of stresses through the thickness of butt-straps. Consequently, a good contact between splice plates is very desirable in order to reduce the stress concentrations in the fillets. However, even in case of perfect contact between splice plates and main plates the stresses will vary through the thickness of splice and main plates in the neighborhood of the fillet. A strain gage attached to the main plate close to the fillet will register high stresses while the same gage placed on the outside of a butt-strap will show low stress. This phenomenon is referred to later as "skin effect."

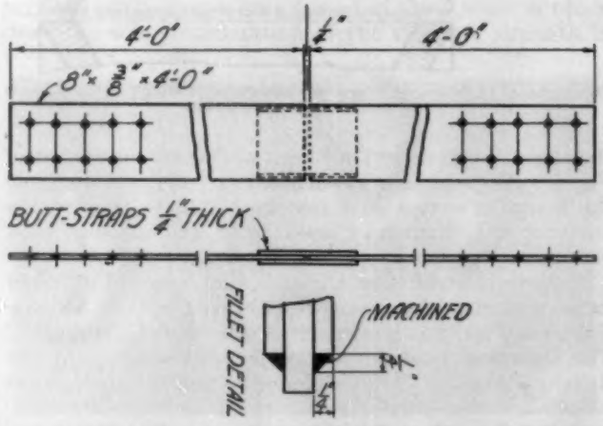


Fig. 7—General Detail of Specimens Showing Method of Gripping

Description of Welded Specimens

Five specimens of double butt-strap joints designed for direct tension loads were fabricated in the shops of the university. A sketch of a typical specimen is shown in Fig. 7. All five specimens were alike with the exception of size and shape of butt-straps and the amount of welding. The main plates were 8 in. by $^3/_8$ in. by 4 ft. long. This length was used to obtain uniform stresses between the end connection and the welded splice, in order to eliminate the effect of local stresses, due to gripping upon the stress distribution in the region of the weld. The ends of each specimen were provided with ten $1^1/_{16}$-in. round holes and fitted into special grips which in turn were designed to fit directly into the grips of a 300,000-lb. Riehle, screw power, balance beam, machine.

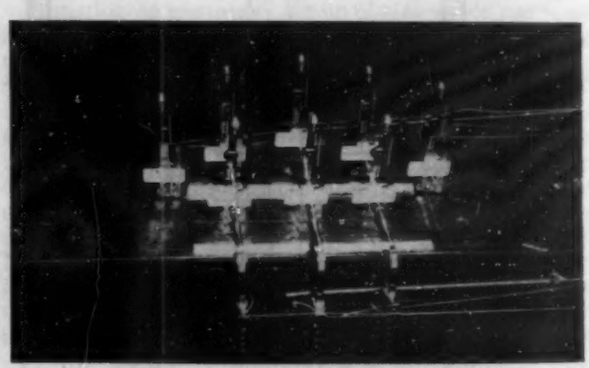


Fig. 8—Specimen 2 with Tensometers in Position

The five types of splice tested are shown in Fig. 1. Detailed dimensions are given in key sketches on Figs. 9 to 13. All splice plates were $^1/_4$ in. thick. All welds were $^1/_4$ in., 45-deg. fillets machined to dimensions. It should be noticed, however, that such procedure does not guarantee the exact size of fillets, due to unequal penetration of metal in the throat of the weld. The total length of fillets was 20 in., 40 in., 34 in., 29 in. and 28 in. for specimens 1 to 5, respectively. All plates were medium structural steel. As no destructive tests were contemplated, the values of ultimate strength of the material, elongation, etc., were not needed. The

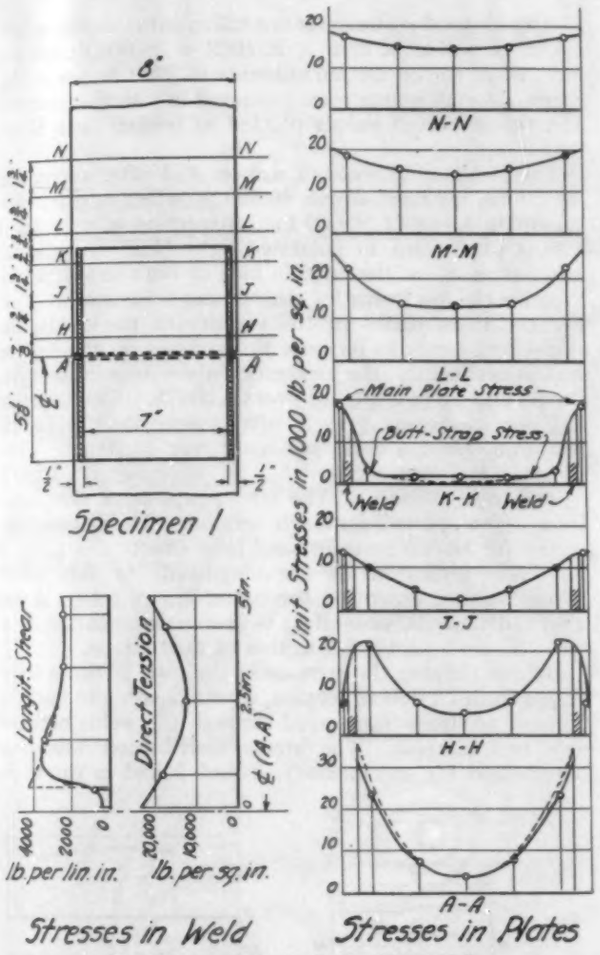


Fig. 9—Stress Distribution in Specimen 1

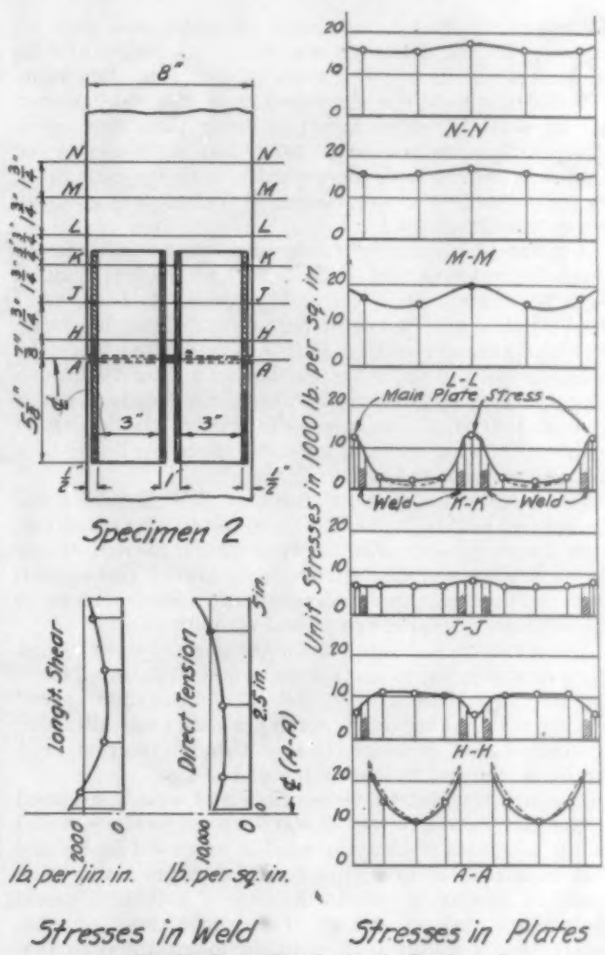


Fig. 10—Stress Distribution in Specimen 2

value of the modulus of elasticity was taken as 30,000,000 lb. per sq. in. with any actual deviation from this figure well within the limits of accuracy of the test. A mild steel dusted welding rod was used.

Care was taken to straighten the specimens before testing in order to eliminate, as far as possible, the effect of eccentricities upon the distribution of stresses. Although the welding was done with more than ordinary care, slight deviation in dimensions occurred. These deviations are noted in the discussion of results.

Testing Procedure

Deformations were measured by means of Huggenberger Extensometers. Half-inch gage length was used. All vertical deformations (in the direction of the pull) were measured on both sides of each specimen in order to eliminate the effect of eccentricity. To insure more accurate results both top and bottom halves of the specimens were fully studied. Thus, four readings were secured for each point plotted on the strain curves. In addition, lateral deformations were investigated in considerable detail at the center-line and edges of splice plates, and in main plates in the vicinity of the splice.

The initial reading of the extensometers was taken with a total load of 10,000 lb. and the load was then raised to 60,000 lb. Thus, the average unit stress at any point did not exceed 20,000 lb. per sq. in. with local stresses probably as high as 40,000 lb. per sq. in. In actual testing no yield was observed at any point.

All measurements on each specimen were made without disturbing or moving the specimen in the machine. To further secure uniform and consistent results, the testing work was so arranged that in testing the entire five specimens the same man set up and read all instruments.

The temperature of the air near the specimen was recorded at the initial and final reading for each set-up. The temperature variation did not exceed 0.5° F. and as the elapsed time between the two readings did not exceed five minutes, it can be safely assumed that the temperature variation of the steel specimen itself amounted to only a small fraction of the total change registered. Specimen 2 with eight extensometers in position is shown in Fig. 8.

Analysis of Data

The measured deformations were first corrected to correspond to an increment of load of 50,000 lb., then were multiplied by 2 in order to get the values of strains in inches per inch. The strains thus found were averaged, multiplied by E and plotted as solid lines. (See Graphs 9 to 13.) Circles on the curves indicate points at which the deformations were actually measured. Each ordinate of the curve is an average of four measured values.

No temperature corrections were made as the variation recorded was too small to introduce deformations of magnitude comparable with deformations set up by the loading.

Smith,[4] Weiskopf and Male[5] determined the stress distribution along side welds by measuring directly the

detrusions of fillets. Although the fillet was only $^1/_4$ in. or $^3/_8$ in. the detrusion was found experimentally for a width of one inch. The value of detrusion thus found included not only the deformation of the weld proper, but as well the deformation of main plate and splice plates within the one-inch zone. The detrusion of the weld was determined theoretically, and by comparing the calculated and the measured values a correction factor was determined.

A different procedure was used to determine stresses along the welds in this study. To find the longitudinal shear per linear inch of the weld between *A-A* and *H-H* (Fig. 9) the total stress in butt-straps through section *A-A* and through section *H-H* was computed from the stress curves and the difference between those two totals gave the stress transferred through the welds between *A-A* and *H-H*. This stress divided by the length of weld ($4 \times {}^3/_4$ in. = 3 in.) gave the shear per linear inch of fillet between *A-A* and *H-H*.

The total stress in butt-straps at *A-A* should equal the applied load of 50,000 lb. The total stress computed from stress curves varies between 42,000 lb. and 46,000 lb. The apparent discrepancy in measured and applied loads is due to three independent causes: errors in observation, lateral restraint and skin effect.

The total stress computed for the main plates through sections above the welds is close to 50,000 lb. in all cases and the amount of error in observation does not exceed two per cent. Thus only a small portion of the difference in applied and measured stress through section *A-A* can be attributed to inaccuracy of testing.

The stresses plotted for section *A-A* and considered in the calculation of the 43,800-lb. total load are based on the assumption that the steel is extended freely and that no lateral forces are involved. Such an assumption would be justifiable only in the case of a definite lateral contraction taking place. The magnitude of this contraction is rigidly related to the longitudinal elongation through Poisson's ratio. As the deformation through section *A-A* amounts to between 0.00016 and 0.00082, the free lateral contraction for Poisson's ratio = $\mu = 0.3$ should vary between 0.00005 and 0.00025. Actual measurement of lateral deformations indicates much smaller values.

Considering a one-inch cube (Fig. 14) subjected to a vertical tension of S_v lb. per sq. in. and a lateral tension of S_h lb. per sq. in. with a measured vertical deformation of d_v and a lateral contraction of d_h, the following relation between the stresses and deformations may be written:

$$\frac{S_v}{E} - \frac{\mu S_h}{E} = d_v$$

$$\frac{\mu S_v}{E} - \frac{S_h}{E} = d_h$$

Substituting 0.3 for μ and solving for S_v and S_h

$$S_v = \frac{d_v - 0.3\,d_h}{0.91} \cdot E$$

$$\text{and} \quad S_h = \frac{0.3\,d_v - d_h}{0.7} \cdot E$$

Applying this formula to a point on *A-A* located $^1/_2$ in. from the edge of the butt-straps with measured $d_v = 0.00082$ and $d_h = 0.00005$ the value of S_v corrected for lateral restraint is:

$$\frac{-0.82 - 0.3 \times 0.05}{0.91} \times \frac{30{,}000{,}000}{1000} = 26{,}600 \text{ lb. per in.}$$

If the lateral restraint is not taken into consideration, the stress would be $0.82 \times E/1000 = 24{,}600$ lb. per sq. in. Thus, the correction amounts to 2000 lb. per sq. in. Stresses for all points were corrected in a similar manner and the corrected values plotted as broken lines (Figs. 9 to 13).

The total stress through section *A-A* after correction for lateral restraint equals 46,300 lb. which is still below the applied load of 50,000 lb. Inspection of a model of a butt-strap joint in polarized light (Fig. 6) indicates lower stresses on the outside face of butt-straps, which explains the low value for the stresses measured at *A-A*. For the main plates in the vicinity of the welds, the skin effect tends to increase the stresses on the surface and, consequently, the measured values for such sections should add up to a total of over 50,000 lb. Thus, section *L-L* for specimens 1 to 3, after correction for lateral restraint, gives a total stress of over 51,000 lb. The same is true for section *F-F* of specimens 4 and 5.

The total stresses in the butt-straps were calculated from stress curves for each section. They were corrected for lateral restraint and skin effect. As there is no direct indication of the magnitude to skin effect in any section, except on the center-line of splice, it was assumed that the skin effect is proportional to the total stress in each particular section of butt-straps.

By determining the increase in the total stress in butt-straps from section to section, it was possible to find the amount of stress transferred through the welds between any two sections. The stress distribution was thus determined for specimens 1, 2 and 5 and is shown in

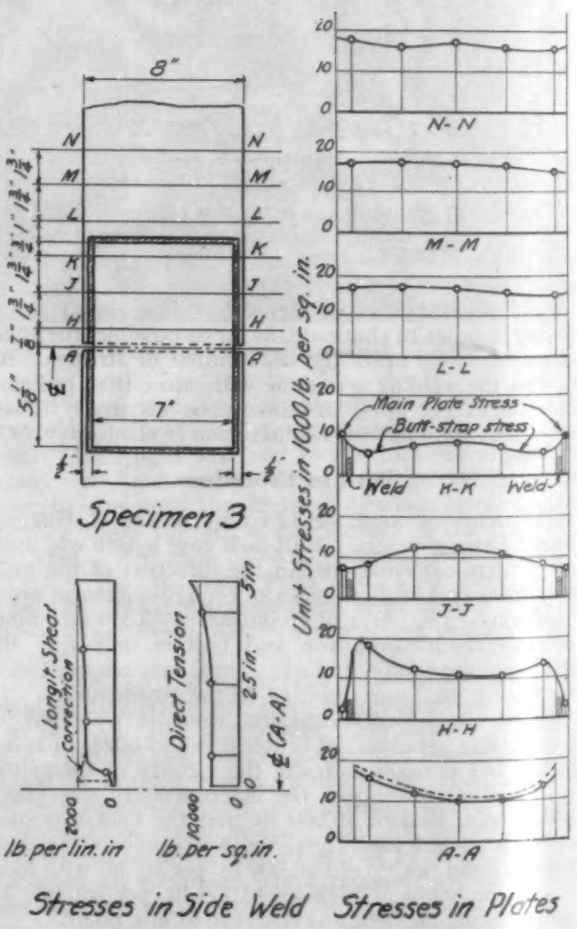


Fig. 11—Stress Distribution in Specimen 3

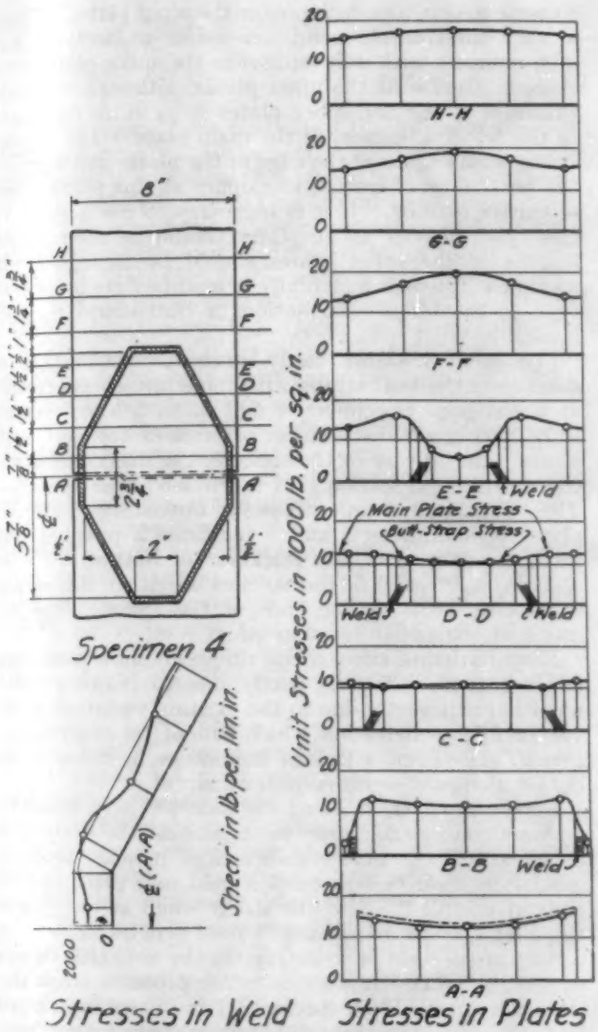


Fig. 12—Stress Distribution in Specimen 4

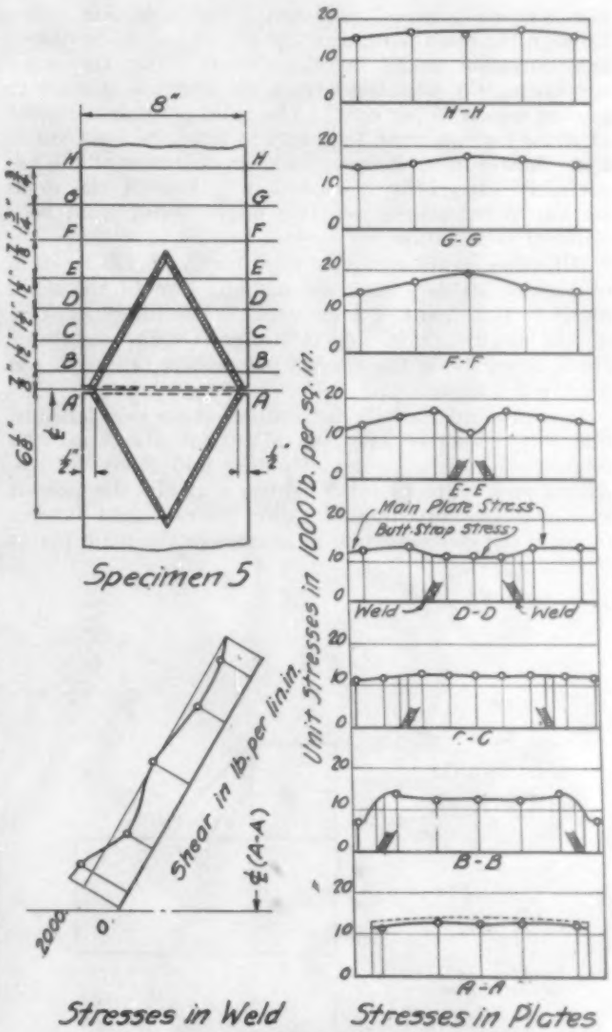


Fig. 13—Stress Distribution in Specimen 5

Figs. 9, 10 and 13, respectively. For specimen 3 the shear per unit length of weld was determined for the intervals between sections *A-A* and *H-H*; *H-H* and *J-J*; *J-J* and *K-K*. These stresses were plotted and connected by smooth curve (Fig. 11) extended beyond *K-K* until it reached the edge of the butt-straps. The area of this stress diagram multiplied by 4 represents the total stress transferred through the vertical welds. By subtracting this total stress from 50,000 lb. the amount of stress carried through the horizontal welds was determined. Only average stress per linear inch of horizontal weld could be found as there were no means to measure directly its magnitude. It is interesting to note that the average stress per inch of weld in both transverse and side welds of specimen 3 is in fair agreement and equals approximately 1500 lb. per in. of fillet for the particular loading used, thus indicating that the transverse and side welds participate to practically the same extent in the stress transfer. The same procedure was used in determining the weld stresses for specimen 4.

In addition to longitudinal shear, side welds are subjected to considerable direct tension. The magnitude of this tension can be found directly from stress curves by taking the ordinate on the center-line of the weld.

Maximum combined stresses will affect the strength of side welds. To determine these combined stresses, consider a 45-deg. fillet with throat T (Fig. 15). Such fillet is actually a three-dimensional system. It can be assumed for simplification of the problem that the stress is transferred from the main plate to splice plates along curve AB with a slope of 45 deg. at the throat of the weld. If the shear equals q lb. per linear in. of the fillet, the unit shear will be q/T lb. per sq. in. Consider an element $CDEF$ with tension N lb. per sq. in. applied across sides CD and EF and shear stresses q/T lb. per sq. in. acting along CE and DF. To satisfy equilibrium conditions, shears of the same magnitude will be induced along the sides EF and CD. The maximum combined stress equals:

$$S = \frac{N}{2} + \sqrt{\left(\frac{N}{2}\right)^2 + \left(\frac{q}{T}\right)^2}$$

Discussion of Results

From a comparative study of the summary stress-distribution curves it is apparent that, under loading within the elastic range of the material, the stress distribution in both main plates and splice plates, as well as in the welds, varies over so wide a range as to make its determination of considerable importance in the design of welded connections.

With regard to main plates, it is seen that specimen 1 (Fig. 9) gives the least satisfactory results with a variation from the average in section *L-L*, from plus 51

per cent to minus 7 per cent. For a section taken through the main plate near the end of the splice plates, this variation would be still greater. For the other specimens, the variations from the average amount to plus or minus 15 per cent. The main-plate distribution of stress for specimen 3 appears to have the least variation; however, it shows certain irregularities which are probably caused by a variation in size of the cross section of transverse welds as might result from non-uniform penetration.

A further disadvantage of type 1 splice is the location of highest stresses near the outside edge of the main plates. This point of high stress is the likely location of the beginning of fatigue failure. Once a fatigue crack develops on the edge, a progressive failure of the joint will follow.

It is evident that the distribution of stresses depends, not only upon the type of splice, but also upon the relative thickness of main plates and splice plates, length and width of splice plates, etc. In the case of specimen 1, shortening of splice plates would further increase the concentration of stresses in the main plates

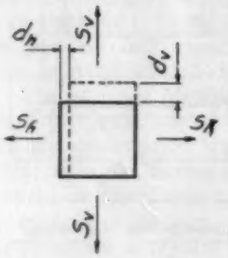


Fig. 14—Element under Biaxial Stress

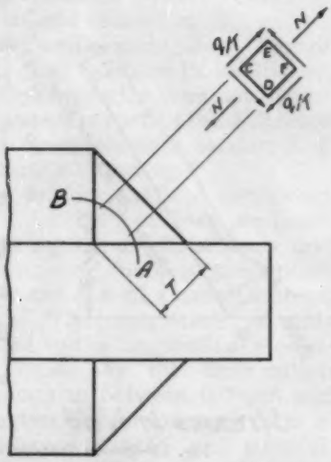


Fig. 15—Stresses in Fillet

at section *L-L*. This can be proved by comparing the stress distribution in the main plates for specimens 1 and 2. The variation of stress in specimen 2 is greatly reduced from that in specimen 1. This is accomplished by the use of two long and narrow splice plates instead of single wide plates. However, the amount of welding in specimen 2 is twice that of specimen 1, and if that amount were reduced to a total length approaching that required by standard design of fillets in longitudinal shear, the splice plates would be much shorter with resulting increase in concentration of stresses along section *L-L*.

If the full section of main plates were designed for stresses of 18,000 lb. per sq. in. the total load would be 54,000 lb. Allowing 2000 lb. per linear inch of $^1/_4$-in. fillet, a total length of 27 in. would be required. Actually specimen 1 has 20 in. of welding while specimen 2 has 40 in. If the length of butt-straps were increased in specimen 1 to provide 27 in. of welding, the stress concentration in main plates would be somewhat reduced. It may prove economical, when fatigue stresses become important, to further increase the length of butt-straps and the amount of welding, thus reducing high local concentration of stresses.

The distribution of stresses in splice plates follows, to some extent, the variation in the main plates. Thus, a very unfavorable condition exists at section *A-A* of specimen 1 with unit stresses in the splice plates even exceeding these in the main plates, although the total thickness of the two splice plates is $^1/_2$ in. as compared to the $^3/_8$ in. thickness of the main plate. The highest stress occurs again at the edge of the plates and suggests the possibility of cracks developing at this point under repetitive loading. If it is necessary to use a splice of this type, heavier splice plates should be used or the lengths of the splice plates should be increased. In specimen 2, which is actually a modified connection of type 1, the stress distribution in butt-straps is more favorable.

Specimen 3 shows fairly uniform distribution of stresses in the butt-straps with moderate concentration at the edges. Specimens 4 and 5, to a lesser extent, show very good distribution of stresses through butt-straps; and in case of the splice 5, the maximum stress concentration in section *A-A* is removed from the edge. The comparison of unit stresses in butt-straps and main plates of specimens 4 and 5 indicates a possibility of further reduction of the thickness of butt-straps. On specimens 3, 4 and 5, the stresses on either side of the transverse welds at the ends of the splice plates are modified somewhat by skin effect.

Distribution of stress along the welds show somewhat less regularity. This is partly due to indirect determination and partly due to the existing variation in the size of fillet penetration which cannot be easily determined. However, a lack of uniformity in stress distribution along the welds is quite apparent.

Longitudinal shear along the side welds in specimen 1 shows considerable drop in stress near the center-line of splice. Theoretical considerations indicate that the maximum shear in side welds should take place at both ends of the fillet. The low stress found at one end of the fillet may be attributed to poor penetration in that section of the weld or to damage in the weld that cannot be seen by surface inspection. The probable stress distribution in welds of specimen 1 is shown by dotted line (Fig. 9). The shear distribution curve for specimen 2, which is of similar type, is in good agreement with theory.

The side welds in specimen 3 are stressed uniformly except for the portion of weld near the center-line of the splice. The distribution of shear along the welds of specimens 4 and 5 is fairly uniform; however, specimen 5 shows better results.

In all types of connections, the fillet weld is subjected to direct tension (considerable in some cases) and to transverse loads in addition to longitudinal shear. These transverse loads may be large, as in the case of horizontal welds in specimens 3 and 4, or relatively small as in the other joints tested. In specimens 1 and 2, however, large transverse stresses are induced in the sections of welds near *A-A* and *K-K*, due to a difference in the amount of lateral contraction in main plates and butt-straps. At *A-A*, for instance, splice plates are heavily stressed and tend to contract a great deal, while the main plates near *A-A* have practically no stresses, thus preventing free contraction of butt-strap and setting up transverse stresses in the fillets. The magnitude of such stresses can easily be determined by using the expression for S_h derived before. The horizontal stresses thus found for butt-straps in the vicinity of the weld will be carried through the fillet.

For a point located $^1/_2$ in. from the edge of butt-straps in section *A-A*, the lateral stress caused by restraint equals:

$$\frac{0.3\,d_r - d_h}{0.7} \cdot E = \frac{0.3 \times 0.00082 - 0.05}{0.7} \cdot E =$$

8500 lb. per sq. in.

For the $^1/_4$-in. thick butt-strap the lateral stress per linear inch equals 2150 lb. and is considerable as compared to the longitudinal shear stress transferred through the same weld (Fig. 9). This lateral force acting upon the weld in longitudinal shear, combined with a great deal of variation in the distribution of shear stress, seems to indicate that ample welding should be specified for wide splice plates of the type of specimen 1.

Tests conducted by H. E. Grove[8] and Peter Gillespie, C. A. Hughes, K. B. Jackson, J. H. Fox[9] and Andrew Vogel[10] on double butt-strap joints with side welds only, and with transverse welds only, showed definitely that the ultimate strength of a side weld per linear inch is considerably lower than that of a transverse weld. For a $^1/_4$-in. weld the value of about 7000 lb. was found for side welds as compared to about 10,000 lb. for transverse welds. This apparent weakness of side welds may be explained by the fact that, in addition to longitudinal shear, tension stresses are set up in fillets. The combined stress corresponding to a longitudinal shear of 7000 lb. per linear inch of a $^1/_4$-in. fillet weld with ordinary proportions of the splice will have a magnitude comparable to the 10,000-lb. load on the transverse fillet.

Although a transverse fillet has greater ultimate strength than the side fillet, its fatigue endurance limit may be lower than in the case of side fillets, due to very high local concentration of stress at the edge of the fillet.[7] However, it was shown that a side weld is also subjected to transverse loads of considerable magnitude due to lateral restraint. The stress condition of a side weld thus becomes so complex that it is hard to foresee the behavior of such weld under repetitive loads. Further laboratory study is required in that direction.

All data reported here refer only to stresses produced in the specimens by direct tension loads. Relative suitability of different types of splices may be affected by a change in the method of loading. No consideration is given here to initial stresses introduced during welding. It is intended to investigate the distribution of these stresses later.

[8] H. E. Grove, JOURNAL OF THE AMERICAN WELDING SOCIETY, January 1927.
[9] Report on Tests, Univ. of Toronto, 1927–28, JOURNAL OF THE AMERICAN WELDING SOCIETY, March 1929.
[10] Andrew Vogel, "Design of Joints for Welded Steel Structures," JOURNAL OF THE AMERICAN WELDING SOCIETY, April 1929.

Conclusions

Although only one specimen of each type was tested, each specimen made possible the study of four similar fillet arrangements under the same load. The regularity of stress curves seems to justify the application of the data to actual design, as far as the relative strength of joints based on the elastic distribution of stresses is concerned.

In certain types of joints tested, a variation of stress distribution was found in main plates, spliced plates and welds, to such a degree as to make desirable a consideration of stress concentrations in designing welded joints.

In splices with side fillets only (specimens 1 and 2) the variation of stress was of such magnitude as to justify, in case of a structure subjected to repeated loads, a larger quantity of welding than that required by customary design, based on the assumption of uniform stress distribution in side welds. This additional welding should take the form of increased fillet length.

If a splice of the first type is used, with the total length of splice plates less than twice the width of the specimen, butt-straps should be at least as thick as the main plate, the latter being designed for reduced unit stresses.

Splices with closed-contour welds show better distribution of stress throughout the entire splice.

Transverse and side welds when used in the same joint participate to about the same extent in transferring the load.

The preference for side welds (i.e., parallel to the axis of the member) as compared to transverse welds (i.e., crosswise of the axis of the member) does not seem to be justified, as the stresses carried by a side weld are complex and of high magnitude, and even the ultimate strength of side welds when tested alone is lower than that of transverse welds tested alone. A combination of the two is more desirable than side welds alone.

The diamond-shaped splices show the best distribution of stresses in all elements of the connection with no concentration of stresses on free edges, and it may be considered the most suitable type of connection for structures where rigidity of a joint and capacity to withstand repeated loads are of major importance.

Qualifications for Welders

By VINCENT P. MARRAN

†Paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 5, 1932. Mr. Marran is Vice-President in Charge-of-Sales and Chief Engineer of the Walsh Holyoke Steam Boiler Works, Inc.

IT WAS recognized as early as the year 856 that the training of men to fit them for any occupation is necessary. In the early Anglo Saxon days voluntary associations were formed primarily for protection, and governed by the heads of the particular district in which they were located. Each guild, as these associations were called, was self-sufficient unto itself, containing as it did servants or craftsmen to perform whatever work was necessary for its existence. Young boys were employed as helpers to assist the more skilled craftsmen, and by association and contact with actual work, they, in time, became skilled craftsmen themselves. These early guilds soon outgrew their primitive structure, however, and developed into larger associations formed for political, social and religious purposes, and these eventually developed into the craft guilds, with definite rules and regulations bearing on the qualifications necessary to the mode of living, the amount of pay to be received and the type of training and length of service necessary to become full-fledged journeymen of the various crafts.

The origin of the English craft guild has never been definitely established. It has been contended that this craft guild is really of Roman origin, but this has not been definitely proved.

As the guilds were extended to take in the various

crafts existing at that time, the Government enacted rules making it necessary for them to pay a royal license, and as early as the twelfth century, the administration of these guilds became interwoven with political economy.

To be a member of a guild, first it was necessary for the craftsman to be a true citizen and to be a freeman in good standing. A foreigner could not join until he had proved his position. Wardens or inspectors were appointed as early as the eighteenth century whose duty it was to carefully scrutinize the craftsman's handiwork. They were expected to make an impartial and inquisitorial examination, and in case of detecting any work imperfect, either by reason of roguery or negligence, to confiscate the goods with an unsparing hand, and to bring the offender to justice. The whole character of the craft guild was designed to prevent fraud and the deception of the public. It was necessary for a craftsman to furnish an adequate guarantee of his fitness to join the guild and to produce good work. The guarantee consisted in the fact of his previous apprenticeship, and the evidence of a good moral character.

In order to produce the proper type of craftsman, an apprenticeship period of seven years was, as a rule, necessary. During this period the apprentice was thoroughly trained in his craft, but in no case could he become a journeyman or a full-fledged member of the guild until his seven years had been served.

As the number of skilled workmen increased in the different crafts, the length of service for apprentices was increased in some instances to ten years, and the number of apprentices that could lawfully be employed by any one merchant was materially reduced. Regulation of labor seemed to be in vogue even in those days.

The lives of these apprentices were strictly regulated. By-laws were enacted to regulate their morality and probity. In New Castle, England, for instance, they were forbidden to "danse, duise, carde or mum, or use any gyterne, or use any cut hose, cut shoes, pounced jerkins, or any beards." Any controventions were visited at first with fines, then with distraint or confiscation of tools and finally with expulsion from the society. In 1450 records show that the iron mongers made a by-law as to dress and appearance of apprentices. His hair, it was expressly stated, "must not be allowed to grow so long." At Colchester the innkeepers were forbidden to allow any apprentice to enter their houses on Sunday, while the Corporation of Carlisle forbade the apprentice to go out after ten o'clock at night unless upon his master's business.

This is not intended to be a history of the mediæval guilds of England, but to show that the training and selection of men was essential even in those days. Nevertheless, industries could learn considerably from the early associations of employer and employee.

Many men today start their careers in a temporary situation. They are taken on at a plant upon terms which allow their being dismissed at short notice, and allow of a serious turnover in labor. Under the apprenticeship system, it was a more serious undertaking because, generally speaking, it was irrevocable, the employer and the employee having pledged themselves to a 7-year agreement, and if the employer was to profit by the work of the employee, it was necessary to give him a training that would produce results. To be sure, the apprentice in the old days received little or no money for his wage. He did, however, receive a living, and a training that made it possible for him to become a skilled craftsman.

The apprenticeship system in this country differs materially from that of the early days, and many of our large companies in this country do select their apprentices with considerable care.

In some cases the apprentice is requested to take an examination. Then, if his mark is sufficiently high, he is given a personal interview, and if this interview proves to the satisfaction of the manufacturer that the boy is the proper type to be given this training, a form of contract is then entered into whereby the apprentice agrees to work for a certain period of time under definite conditions, either with or without pay, and the manufacturer agrees to instruct the apprentice in the various phases of the trade that he is undertaking to learn.

Quoting from a pamphlet issued by one of our big industrial concerns giving information relative to apprenticeship in their organization, they state: "We believe if there were full knowledge of the kind of training given and of the opportunity for advancement following an apprenticeship which the future holds out to boys of energy and ability who are mechanically inclined, there would be a greater interest shown in taking up such a form of training. We believe also that there is no adequate substitute for the training as given by a regular apprenticeship. Even a graduate of a technical college must serve some form of apprenticeship if he is to become most efficient in his line of work. Not a smattering of information, but a thorough knowledge of his work is what we believe a young man should have if he is to become successful. His training course must be so planned that he will not only learn how to do things, but will remember how to do them by enough repetition to insure a continued understanding."

In still another company, to be eligible for apprenticeship, a boy must be not less than 16, nor more than 18 years of age. He must have a good common school education, and a sufficient degree of physical development to fit him for the trade. Only boys of good habits whose sight and hearing are unimpaired are accepted. A preliminary examination is ordinarily required to show how much knowledge the boy has of simple mathematics, including fractions, decimals, ratio in proportion, mensuration, etc. Candidates whose examinations and references are satisfactory are then given a twelve weeks' trial period. At the end of this probationary period, if the boy's deportment and attitude are in keeping with the requirements of the industry, he is permitted to continue his apprenticeship.

Welding is little different from other mechanical trades requiring as it does skill in the manipulation of different metals, a knowledge of structure and a carefulness of purpose.

We have numerous types of welding. The electric arc is subdivided in two classifications, the carbon electrode being used as early as 1887, and the metallic electrode being used approximately 2 years later. The acetylene weld was used in commercial production in 1895. Thermit welding, resistance welding, atomic hydrogen welding and other types all have their places in industry, and all have one factor in common, that is, the type of operator that should be employed.

At the present time there is no classification for the welder, and while welding is recognized generally as a trade in itself, still the American Federation of Labor on April 28, 1920, in a matter of dispute between tradesmen concerning the jurisdiction over welding, agreed that "each trade, to have jurisdiction over all acetylene and electric welding when such process is used to perform work of their respective trade." There are so many purposes for which welding is used, that no one welder could possibly master them all.

What should be done is to classify the welder according to the different type of equipment to be used, and his

skill or ability to use it. The welder should then be graded with an A, B, C or D rating, depending on the requirements of that particular industry. Metallic hand welding operators working on sheet metal are not qualified by experience to work on heavier metals. Welders working on heavier metals are not necessarily qualified to work on pressure vessels, and welders working on pressure vessels are not necessarily qualified to work on steam boilers.

Welders under these classes should be obliged to take an examination that would qualify them for the A, B, C or D grade, and not until they have passed a further test should their grading be advanced.

Only in this way can a manufacturer, by qualifying his welders, hope to turn out satisfactory work that will be a credit to the art. Much harm has been done the art of welding by having poor operators on classes of work they are not qualified to handle, and sending it out to the trade, only to have it fail in service.

One insurance company that insures pressure vessels, steam boilers and other products insists on the manufacturer submitting to them samples of welding he is qualified to do in his plant. These samples are tested in a strength of material laboratory for tensile, bend, yield, fatigue and ductility, the samples classified, and if the samples fall within the limits set by the insurance company for satisfactory work, then the manufacturer is placed on the insurance company's approved list, and he is allowed to bid on any work coming under that particular insurance company's control. Before proceeding with any actual construction, he is obliged to show that all welders who will work on vessels have by qualification tests proved their ability to obtain results. Only by this means can the insurance company satisfy itself that its requirements for construction have been met and can they be in a position to assure the purchaser that the vessel will be satisfactory.

Manufacturers should take a leaf from the insurance company's book and qualify their welders in a similar manner.

In the March 1932, JOURNAL OF THE AMERICAN WELDING SOCIETY, Mr. S. Lewis Land has a very interesting article on the welding of pipe where he summarizes welding and the welder, suggesting that the welder complete a course in 16 different units to properly fit him for the particular work described in his article.

We can find numerous references for rules to follow in the selection of welding equipment. We can find numerous rules to follow in the selection of welding wire. Various states have enacted legislation regarding the use of welding equipment, and restricting its use in many instances. The Interstate Commerce Commission lays down rules for shipping containers; the Gas Producers Association on the handling of cylinders; the American Railroad Association on limits and regulations of autogenous welding; the Steam Boiler and Fly Wheel Service Bureau on the requirements of autogenous welding in insured boilers or other pressure vessels for new construction or repairs; the Underwriters Laboratories on standards of construction of acetylene generators, pressure regulators, blow pipes, oxyacetylene welding and cutting systems. The National Board of Fire Underwriters has regulations for the installation and operation of gas systems of welding and cutting; the National Safety Code for the protection of industrial workers.

In no case can we find regulations giving the requirements of the welder who is to meet the above regulations.

There are, to be sure, thousands of welders who are doing satisfactory work, but very few of them can be said to have thoroughly mastered it. To meet the needs of a growing industry, the following are offered as the requirements in the selection of men to be trained in the art of welding:

First—He must be trustworthy.
Second—He must be industrious.
Third—He must be intelligent.
Fourth—He must be ambitious.
Fifth—He must have determination.
Sixth—He must be physically fit.

A welder who is not trustworthy will hurt the entire industry. While he may be perfectly capable of making a good weld, at some time he will slight his work sufficiently, not only to the detriment of the art, but to the detriment of his employer and the customer. A case in point that will better describe this definition is the case of a welder who was working on a piece-work basis hand welding the longitudinal seams of a series of tanks $^{3}/_{8}$ in. thick. His record of performance was splendid, his output nearly 50% greater than that of his associates, and when the matter was checked up to find why his speed was so much greater, it was found that he was dropping $^{3}/_{16}$-in. welding rods in the groove and welding over the top of the rod, making a good weld over the rod, but depositing considerably less metal, and a poor weld as far as strength was concerned. His contention, when he was questioned, was that the tanks were really not pressure vessels, but merely containers, and his weld was good enough. Numerous instances of a similar nature could be quoted to confirm the statement that trustworthiness is absolutely necessary for good welding.

A welder must be industrious if he is to succeed at his trade. He must like the work he is doing, must be able to apply himself without watching the clock and be what is generally known as a good worker.

Intelligence is a third essential. He should be endowed with the faculty of reason, and should be well informed. If he has a technical education, so much the better. A knowledge of metallurgy is important. A knowledge of the fundamentals of electricity will help. He must be quick to grasp the essentials, and to realize that in order to progress in his work, study and practice are necessary.

He must be ambitious so that he will grasp every opportunity for his advancement. When he realizes that he must first learn to creep before he can hope to walk, then he will take every means allowed him to have his standard of work on an equal or better basis than that of his associates. Ambition is the desire to do the work just a little bit better than the next man, and if a welder has this characteristic in his makeup, he will go far.

He must have the determination to master the intricacies of the art. He must have resolution, purpose and decision. Only by being determined can he become an expert welder with all the qualifications that are necessary to make him really and truly expert.

He must be physically fit. There are certain hazards in welding that require physical fitness to combat. Different classes of welding require different qualities of physical fitness, and the extent of physical fitness would necessarily be governed by the class of welding to be performed.

The responsibility for the proper training of operators necessarily falls on the manufacturer. In the manufacturer's haste to put men on a productive basis this training becomes more or less superficial in many instances.

Therefore, it is suggested that a time clause be placed in the qualifying code for welders so that, regardless of the skill an operator may develop in a short length of time, he will have had sufficient experience before qualifying for the next step. If the operator is a technical

graduate he will undoubtedly require less time than the operator who has not had his advantages of education, and a certain leeway should be left with the manufacturer as to the length of time for proper qualification.

It has been remarked that the A. S. M. E. code creates a hardship for the small manufacturer, but if the standard of welding is not kept at a high level, the results would be harmful to the art. If proper qualifications were outlined and welders classified in accordance with their ability, the small manufacturer could employ good welders and put out as satisfactory work as the larger manufacturer.

It is to be hoped that serious consideration will be given, not only to the classification of welders, but to the gradation of welders in the hope that the future will bring us less "metal gluers," and more good welders.

Oxyacetylene Cutting as Applied to Railroad Car and Locomotive Scrapping

By W. H. LUDINGTON

✦Paper was presented at Fall Meeting of American Welding Society in Buffalo, Oct. 3, 1932. Mr. Ludington is Manager, Applied Engineering Dept., Air Reduction Sales Co., New York.

Introduction

RAILROAD car and locomotive scrapping are operations of growing importance to the railroads, the waste material or scrap dealers, and the oxyacetylene industry. Railroads are vitally interested from the standpoint of operating economies and inventories.

Undoubtedly the oxyacetylene cutting torch is the major and most important tool employed for this work. Without it, the operations could not be carried out on the present profitable basis, as the cost of scrapping by entirely mechanical methods would, in most cases, be prohibitive.

Scrapping Practice

When railroad equipment no longer serves economically the purpose for which it was designed, it should be scrapped, provided this can be done at a profit.

Railroads make tests to determine their own scrapping costs and available profits from the sale of the scrap, and compare these against the price offered them by outside concerns for the equipment on wheels. If, as a result of this study, they decide that it would be more profitable to do the work themselves, they install their own scrap and reclamation plant for this purpose. Otherwise, the equipment is sold on wheels to a contractor for scrapping.

Extensive scrapping programs are usually conducted in well-appointed central scrap and reclamation plants. In many cases the work is done in the open, but shops are also used, particularly during cold weather.

Wooden box cars are often burned out-of-doors as the first scrapping operation. The body bolts that hold the body to the underframe are cut with the oxyacetylene torch, and the body is dumped off the trucks on its side. Greasy waste from the journal boxes is spread around inside the body and lighted to start the fire. The steel framework is later lifted out of the ashes with crane magnets and moved to the location where it is scrapped with cutting torches. The underframe and trucks remain on the track and are rolled away to be scrapped separately.

At other points, however, the cars are not burned and the good lumber salvaged from them is used for walks, cement forms, temporary buildings, and the like.

In scrapping all-steel gondolas, the usual procedure is to cut the top rail first. Then the sides and ends are removed. The hoppers and bottom, brake rigging, cross members, center sill and trucks follow, in the order named.

It is evident that there is a wide variation in the correct scrapping procedure for the many different types of cars in use. The cuts to be made with the torch depend largely upon shop equipment also. If shears are available, the car sides and ends need only be gas cut to a size which can be handled under the shears, where the larger pieces are reduced to charging box size (5 ft. x 18 in.). By using shears, less linear feet of gas cutting per car are required and scrapping costs are lowered.

Locomotives do not vary as widely in their construction as cars and scrapping procedures employed are more uniform. The locomotive is stripped and the boiler raised off the frame and running gear. From an oxyacetylene standpoint, the largest scrapping operation is the boiler. The superheater equipment is removed and the flues and staybolts cut out. Both the shell and fire-box of the boiler are gas cut to sizes which can be handled under the shears for further reduction. The frames and bed are gas cut, and other parts. Running gear and trucks may be dismantled in a systematic manner so as to avoid excessive cutting wherever possible. Scrapping locomotive tenders is an operation similar to that of scrapping all-steel gondolas, which has been mentioned earlier.

Both cars and locomotives may be scrapped in position by completely demolishing them in one location, or by the line method, moving them along from point to point until the operation is complete.

The line method entails performing the same operation repeatedly at any given point in the line. It is usually more systematic and economical where extensive programs are involved and where considerable numbers of varied parts are salvaged for re-use, these parts being sorted out at the various stations.

Whichever method is employed, the types of cars or locomotives to be scrapped should be carefully surveyed beforehand to determine the most efficient and economical scrapping procedure. This includes determination of the most advantageous lines for gas cutting to complete the job with the minimum number of linear feet of cutting, per car and per ton of scrap, and the lowest possible cost. Once established, the location and order of the cuts should be strictly followed.

Facilities Employed

The facilities employed in car and locomotive scrapping consist of oxyacetylene cutting outfits, pneumatic tools,

Table 1—Oxyacetylene Set-Up for Line Scrapping Sixteen Wooden Box Cars per Eight-Hour Day

Position No.	Average Amount of Cutting, per Car	No. of Operators	Average per Car, Cu. Ft. Oxygen	Acetylene
1	170—1/2-in. and 3/8-in. bolts 12—1 1/4-in. rods	2	54	18
2	200—3/4-in. and 24—5/8-in. transom and draft bolts; 10—1-in. and 2 7/8-in. rods	3	50	13
3	None	..	...	..
4	None	..	...	..
5	None	..	...	..
6	None	..	...	..
7	56—7/8-in. side post rods 28—3/4-in. car line rods	1	36	8
8	None	..	...	..
9	4—1 1/4-in. bolts; 10—1-in. bolts 8—7/8-in. bolts; 24—3/4-in. bolts 56—5/8-in. bolts; 12—1 1/4-in. arms	2	70	15
10	16—3/4-in. bolts	1*	4	1
11	32—1 1/4-in. bolts; 32—1-in. bolts 32—3/4-in. bolts; 16—5/8-in. bolts 26 linear inches, 1/2 in. thickness	1	54	12
12	Two car bolsters	1	29	5
	Totals	11	297	72

* Part time only, assisted in other work also.

alligator shears, hydraulic baling presses for thin scrap, coupler pocket shears, magnetic separators for segregating brass and non-ferrous scrap, babbitt melting furnaces, and the like.

Scrap handling equipment consists of cranes of overhead bridge, gantry, locomotive, truck or crawler type; steam, gasoline or electric driven. Crane magnets of from 24 to 140 in. diameter are used, depending on the work. Skids and racks, wagons, trailers, hand and electric lift trucks and gasoline tractors are employed, at different points. Scrap containers, sorting pans and nesting boxes of one to ten tons capacity are often used and storage bins for sorted scrap may be provided where it is held for a price.

A. R. A. Scrap Classification

Ordinarily, all scrap is cut and shorted to agree with the American Railway Association Scrap Classification. This includes about twenty different classes of scrap such as arch bars, axles, busheling, cast steel, cast iron, melting steel, steel spring, structural steel shapes and copper.

Unless special conditions exist, this practice should be closely adhered to as sorted scrap can be sold to advantage to a wider market. The proper sorting of scrap into these classifications materially increases the volume of material for reclamation and re-use as well as the returns received from that sold.

Materials Salvaged

When cars and locomotives are scrapped, many parts are salvaged and re-used for repairs or new equipment. In cases where the scrapping is done by outside concerns, the railroads often buy these parts back from them.

General items to be salvaged from cars are angle cocks, brakebeams, brake cylinders, brake levers, brakeshoes, cast steel trucks, couplers and knuckles, coupler yokes, cutout cocks, draft castings, draft gears, draft followers, journal bearings, journal boxes, lumber, release valves, reservoirs, retaining valves, triple valves and wheels. Of course some of these items will require reconditioning. Where space exists, cast steel trucks and other equipment may be stored and shipped as and when required for program work.

One scrapping program for 2000 cars produced 29,729 tons of salable scrap, 1888 tons of recovered material in usable condition, or approximately 6 per cent by weight and, in addition, 400,000 board ft. of re-usable lumber.

General items to be salvaged from locomotives consist of air pumps, air reservoirs, brake cylinders, brake rigging, bells, couplers, fire doors, injectors, inspirators, journal bearings, lagging, lubricators, miscellaneous valves, motion work, shoes and wedges, steel wheels, whistles and headlight equipment. In cases where the type has not become obsolete, recovered material may amount to 25 per cent of the total scrap, by weight.

Weight of Classified Scrap

The average weight of classified scrap obtained per car, for various types of cars, as compiled by the American Railway Association (Circular No. D-VI-279) from data received from the railroads was as follows:

Average Weight of Classified Scrap from Cars

Composite gondolas, flat hopper bottom, steel center sills	21,295 lb.
Composite gondolas, flat bottom drop ends, steel center and side sills	31,442 lb.
Hoppers, all-steel	35,010 lb.
Flat cars, steel center sills	20,140 lb.
Gondolas, all-steel, twin hopper bottom	38,970 lb.
Single sheath box cars, steel frame and steel underframe	29,358 lb.
Double sheath box cars, wood body and steel center sills	22,446 lb.

With locomotives and tenders, practically the entire gross weight is obtained as classified scrap and recovered material.

Labor and Material Requirements

Labor and material requirements for car and locomotive scrapping will, of course, vary with the type of rolling stock, the facilities employed and the output. Data collected from a railroad by the American Railway Association in one instance were as follows:

Dismantling Cars

Type of plant.....Central scrap and reclamation
Output per month.....141 cars
Handling equipment.....Overhead crane
Average cost per car.....$25.77
Value gases used per car.....$ 9.34

Trade	No. of Men Engaged	No. of Man-Hours per Car
Torch operators	6	9
Laborers	7	10
Shearman	1	0.5
Shear helpers	3	2.5
Craneman	1 (50% crane time)	1
Stockkeeper	1	1
Totals	19	24

Data on locomotive scrapping, also obtained from a railroad and compiled by the American Railway Association, are reproduced below:

Dismantling Locomotives

Type of plant.....Central scrap and reclamation
Output per month.....28 locomotives
Handling equipment.....Overhead and locomotive crane
Average cost per locomotive...$134.71

Trade	No. of Men Engaged	No. of Man-Hours per Locomotive
Torch operators	6	35
Mechanics	5	18
Laborers	2	12
Helpers	11	65
Craneman	1	12
Totals	25	142

Gas Consumptions and Gas Ratio

Data which we have collected indicate that, where the work is efficiently done, the gas consumptions for car scrapping will average approximately as follows:

Average Gas Consumptions per Car for Scrapping

Type of Car	Oxygen	Acetylene
Flat cars	770 cu. ft.	190 cu. ft.
Wooden box cars	300 cu. ft.	70 cu. ft.
All-steel gondolas	1150 cu. ft.	290 cu. ft.

While all-steel cars require the most gas, the amount of classified scrap obtained from them is increased in proportion.

Cutting tips equivalent to our Style 24 No. 2 cutting tip, operated at 40 to 50 lb. per sq. in. oxygen pressure and 4 to 5 lb. per sq. in. acetylene pressure have been found most economical for average car scrapping work. The average ratio of oxygen to acetylene ranges from 4 to 4.5 to 1. On line scrapping smaller tips can sometimes be used advantageously at certain positions in the line.

Wage Systems

To guard against waste of gases and other materials used in car and locomotive scrapping, piece-work rates are sometimes established which permit these supplies to be charged against the men using them. This system tends to discourage the use of oversize tips or excessive oxygen and acetylene pressures by the torch operators.

Comparative Cost Data

Comparative cost data for car scrapping were secured from a railroad which scrapped 2190 cars, of various types, by the American Railway Association.

Labor costs per car ranged from $11.48 for flat cars to $22.90 for all-steel cars. Material costs per car ranged from $9.73 for flat cars to $13.03 for all-steel cars. Total costs per car ranged from $21.21 for flat cars to $35.93 for all-steel cars.

Average scrapping costs for all cars were: labor, $21.08; material, including gases, $12.33; total, $33.41.

To obtain classified scrap at an average cost of only $2.29 per long ton, from obsolete equipment, is undoubtedly profitable, even where shipping and other moderate costs must be added to this total. Furthermore, as has been pointed out, as much as 6 per cent by weight of this scrap may consist of re-usable parts in good condition, which are worth much more than scrap to the railroads.

The data collected on locomotive scrapping indicate an average cost of approximately $1.30 per long ton for labor and material, including gases. Gases alone approximate $.35 per long ton. Obsolete locomotives are, therefore, even more profitable to scrap than cars. They likewise yield a large number of re-usable parts.

Conclusion

In conclusion, it may be stated without reservation that obsolete railroad car and locomotive scrapping operations, where carried on systematically and efficiently, are profitable. The practice has become definitely established on a sound economic basis and will continue to grow as it is more generally adopted.

From a by-product, scrap has become an important raw material. The scrap or waste material dealers have become, from collectors of waste products, conservers of genuine national wealth.

The railroads are giving the most careful attention to all expenditures and every possible source of additional income. They recognize the necessity of conserving and reclaiming materials, of which activity railroad car and locomotive scrapping is an important branch. In this work, the major tool, which assures them a profit, is the oxyacetylene cutting torch.

The Chemistry of Low-Carbon Metal-Arc Weld Metals

By **J. C. HODGE**

✦Paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 5, 1932. Mr. Hodge is connected with the Babcock & Wilcox Company.

SPECIFIC physical properties of any metal or alloy, in which the engineer is primarily interested, are dependent upon the conditions revealed by the following studies of the metal:

1. Radiography or macro examination of gross defects.
2. Micro or X-ray metallography or study of small structural units, and—
3. Chemistry or composition of the alloy.

The composition of an alloy is fundamental, being fixed by the conditions of the melting process, and only in exceptional cases is it changed to any appreciable extent by subsequent mechanical or thermal treatments; for example, decarburizing, nitriding or case hardening. Being of a fundamental nature, the composition of an alloy is usually limited in engineering specifications to a definite range for each of the elements of the alloy. A specification for welded joints is yet to appear, however, in which the composition of the weld metal to be used is designated, in spite of the fact that weld metals vary widely in their composition. This variation in the composition of weld metals originates in variations in the original composition of the electrodes and in changes from the original electrode composition occurring during the arc transfer of the weld metal.

Electrode or Welding Wire

Usually the welding of a metal does not permit much latitude in the choice of an electrode in regard to its chemistry. Given a base metal to weld, an electrode of the same composition is invariably chosen to perform the welding. Where considerable loss of any element may occur during the transfer of the molten metal from the electrode tip to the weld, due either to volatilization of the element, or to excessive oxidation of the element, and where it is important that the weld metal should closely approximate the base metal in analysis, it may be necessary to use an electrode originally higher in the content of the element to compensate for its loss in the arc transfer.

All of the electrodes from which the various types of weld metals in this investigation were deposited

were the same, conforming to Specification EIB of the AMERICAN WELDING SOCIETY, with the following analysis:

Carbon	0.13–0.18
Manganese	0.40–0.60
Silicon	Not over 0.08
Sulphur	" " 0.04
Phosphorus	" " 0.04
Nitrogen	(Not specified but will be approximately 0.007%)

The effect of surface materials on electrodes in determining the quality of welded joints in a given metal is greater than the effect of any other single factor, and sometimes greater than the effects of a combination of several factors. For any given electrode, the working qualities of the electrode and the entire char-

Fig. 1

acteristics of the weld metal may be changed at will by changing the character of the materials on the electrode surface. The surface materials are usually nonmetallic and affect the characteristics of the metal-arc in several ways:

1. Stabilizing the arc by supplying a material, readily volatile below arc temperatures, which provides a conductor for the passage of the welding current when the dropping of a ball of molten metal from the tip of the electrode would otherwise momentarily extinguish the arc. For this purpose only a very small quantity of surface material is required, this quantity being supplied either as a remnant of the lime, soap or iron oxide lubricant used in the drawing of the wire or as a loosely adhering dust. Very thin coatings may also be supplied.
2. Protecting the molten metal from the gases of the surrounding atmosphere. For this purpose a heavy coating or covering is applied to the electrode. During welding this covering melts uniformly with the metal core of the covered electrode, and the molten flux or slag encloses either partially or entirely the arc, the degree of protection varying with the completeness and thickness and nature of the molten slag. Unless the covering supplies a molten flux or slag of the proper viscosity and melting point, there is always danger of entrapping large bodies of slag in the weld metal, producing a major defect in trying to eliminate microscopic defects such as nitrides and oxides.
3. Formation of a heavy slag over the deposited bead of weld metal which retards the rate of cooling of the bead, thus allowing more time for the contraction of the weld metal to take place.
4. Formation of a fluxing material which produces wetting of the base metal with more ready fusion of the base metal and weld metal.
5. The molten slag characteristics, melting point, viscosity, chemistry, etc., will affect the arc and weld metal. Reactions may progress between molten metal and molten slag, these reactions being either desirable or undesirable according to the relationship between the chemistries of the slag and the metal.

Chemistry of Bare Electrode Weld Metals

While the temperature of the metal-arc is certainly not uniform throughout the length of the arc, the cathode hot spot possessing the highest temperature, intensely high temperatures prevail throughout, these temperatures being of the order of 5000° F. (2800° C.). At temperatures of this magnitude the gases of the atmosphere, chiefly nitrogen and oxygen, must be exceedingly active chemically. Probable ionization of these gases further enhances their chemical activity. The metal melting from the tip of the electrode, traverses the arc in a more or less steady stream of molten globules and vapors. This combination of extremely high temperature and relatively large surface area of the metal in passing through the arc readily permits chemical reactions between the nitrogen and oxygen of the atmosphere and the elements of the molten metal. Oxidation and partial elimination of the carbon and manganese of the weld metal occurs, and, at the same time, iron and possibly manganese nitrides are formed and absorbed by the molten metal. Iron and manganese oxides are also absorbed.

Several analyses of arc weld metals, deposited from bare electrodes, which offer no protection to the molten metal, are given in Table 1:

Table 1—Chemical Composition of Bare Electrode Weld Metals

	1	2	3	4	5	Average
Carbon	0.023	0.022	0.022	0.014	0.022	0.021
Manganese	0.20	0.29	0.20	0.13	0.27	0.22
Silicon	0.007	0.010	0.007	0.010	0.010	0.009
Sulphur	0.025	0.027	0.025	0.043	0.036	0.031
Phosphorus	0.018	0.017	0.012	0.015	0.023	0.017
Nitrogen	0.155	0.110	0.107	0.121	0.133	0.125

A comparison of the above analyses of the deposited weld metals with the analysis of the original electrode shows that the carbon content has been reduced to a negligible amount, that the manganese content has been reduced to approximately one-half the original value of the electrode and that a tremendous absorption of nitrogen has taken place.

The extremely oxidizing conditions of the metal-arc is further indicated by the analysis of weld metal deposited from an electrode of high manganese and silicon contents. The larger amounts of these two elements are purposely used to secure protection of the iron without the formation of FeO, by reason of the preferential oxidation of the silicon and manganese, the SiO_2 and MnO so formed uniting to form a manganese silicate slag, which floats to the surface of the weld metal bead.

	Carbon	Manganese	Silicon	Sulphur	Phosphorus	Nitrogen
Electrode	0.11	0.90	0.52	0.027	0.018	0.007
Weld Metal	0.012	0.44	0.21	0.030	0.018	0.079

The use of high manganese and silicon in the original electrode has probably been only partly efficacious, for, as shown in the two analyses, the carbon has been eliminated to the values of Table 1, and a large amount of nitrogen has been absorbed. Both the manganese and silicon contents have been reduced to less than 50 per cent of their original values.

It has previously been stated that the formation and absorption of iron oxide and nitride by the molten metal must progress rapidly at the temperature of the metal-arc. Herty[1] has shown that the solubility of oxygen

[1] C. W. Herty, "The Physical Chemistry of Steel Making. The Solubility of Iron Oxide in Iron," *Mining and Metallurgical Investigations, Bulletin No. 34.*

Table 2—Chemical Analysis of Metal-Arc Weld Metals

	Weld Type	Degree of Protection	Carbon	Manganese	Silicon	Sulphur	Phosphorus	Nitrogen	Insoluble Residue Ins. in Iodine	Insoluble Residue Ins. in Nitric
1.	Bare Electrode	No protection	0.022	0.20	0.007	0.025	0.012	0.110	0.028	0.022
2.	Covered Electrode, slag producing type, long arc	Minimum protection from covered electrode	0.06	0.30	0.10	0.023	0.017	0.07	0.064	0.060
3.	Covered Electrode, slag producing type, medium arc	Medium protection from covered electrode	0.10	0.36	0.10	0.020	0.019	0.05	0.040	0.036
4.	Covered Electrode, slag producing type, short arc	Maximum protection from covered electrode	0.11	0.41	0.10	0.021	0.020	0.027	0.076	0.080
5.	Covered Electrode, slag producing type, short arc and secondary protection	Maximum protection	0.11	0.43	0.10	0.029	0.024	0.015	0.076	0.054
6.	Bare Electrode, gas protection		0.08	0.50	0.01	0.026	0.020	0.031	0.012	0.008
7.	Covered Electrode, gas producing type		0.075	0.50	0.15	0.034	0.019	0.019		
	Original Electrode		0.13–0.18	0.40–0.60	0.08 max.	0.04 max.	0.04 max.	0.005		

in pure iron under a pure FeO slag is equal to 0.30% oxygen at 1600° C. and 0.45% at 1700° C., the solubility of oxygen in pure iron for the temperature range investigated being expressed by the following empirical straight line equation:

$$\text{per cent oxygen} = 0.001475° \text{ C.} - 2.058$$

For the moment, let us disregard actual conditions in the metal-arc, neglect the dissociation temperature of FeO, etc. If the above equation could be applied for the temperature of the metal-arc, and if the metal of the arc could be held at that temperature under a bath of pure iron oxide for a sufficient period of time to establish equilibrium conditions, the oxygen content of the metal would be approximately 2.08% and the FeO content of the bath would reach the figure of 9.5%. If cooling of this high temperature metal should proceed slowly, the solubility of oxygen in the metal would progressively decrease to about 0.20% at the freezing point (1520° C.), the excess oxygen separating out of the molten bath as globules of FeO and rising to the slag on the surface of the metal.

The above is not given as even a suggestion that actual conditions in the metal during its transfer through the arc even approach the extremely high oxygen content, obtained under the above admittedly erroneous line of reasoning It is presented merely to convey a qualitative condition, namely, that in the metal-arc, conditions are present tending to produce oxygen and FeO contents in the deposited metal far in excess of that obtained in low-carbon iron, which has been cast from normal melting temperatures.

Ziegler[2] has reported values for oxygen in two metal-arc weld metals (vacuum fusion method) as 0.183 and 0.259. It should be noted that these two values approximate the value of 0.20% oxygen, obtained by Herty as the equilibrium amount of oxygen soluble in pure iron at the freezing point (1520° C.). If the electrodes from which these two weld metals were deposited contained 0.15% carbon, they would have originally possessed oxygen contents of the order of 0.035%. That the oxygen content of bare electrode weld metal is not higher than the two values reported is due to four conditions present in the transfer of the metal through the arc:

1. Much of the iron oxide formed at the interface of molten and vaporous iron and the atmosphere is carried from the arc as a vapor.
2. The iron oxide vapors so formed tend to protect the metal of the arc from further oxidation.
3. The transfer of the metal through the arc occurs in a steady stream and the time interval involved is exceedingly short, and,
4. Excess oxygen separates out as FeO which rises to the surface of each weld metal bead as a slag, which is removed before a succeeding bead is deposited.

In the metal-arc this extremely high temperature steel or iron with its abnormal quantities of nitrogen and oxygen is deposited upon the cold or at least relatively cold parent or base metal, and the temperature of the weld metal drops to its freezing point within two or three seconds. Equilibrium conditions cannot be established, so that it is possible for a weld metal at the moment of solidification to be in a supersaturated condition with respect to the solubilities of oxygen and nitrogen.

Chemistry of Covered Electrode Weld Metals

Inasmuch as the brittleness of bare electrode weld metal has been attributed rightly or wrongly to the extremely high nitrogen and oxygen contents of the order given above, all attempts to produce high quality weld metal have been centered on the protection of the molten and vaporous weld metal from the atmosphere during its transfer through the arc. This protection is accomplished by surrounding the arc with an envelope of neutral or reducing materials. This envelope may consist of an artificial atmosphere of gases such as hydrogen or may consist of a sheath of molten slag, produced from the melting of a non-metallic covering on the bare electrode core. The protection may be secured by the use of a combination of the two, or may be secured by the use of an electrode covering which is partially slag producing and partially gas producing. The efficiency of any particular method in giving protection will, of course, vary depending upon other factors. For example, for a given covered electrode design, varying amounts of nitrogen and oxygen may be introduced into the weld metals by merely changing the length of the arc. This effect is shown in Table 2.

Welds 2, 3 and 4 show the changes in composition

[2] N. A. Ziegler, "Solubility of Oxygen in Solid Iron," *A.S.S.T. Preprint*, 1931.

Table 3—Change in Chemical Composition of Metal during Arc Transfer

Weld Type	Degree of Protection	Loss in Carbon		Loss in Manganese		Gain in Nitrogen	
		Actual	% Loss of Original Electrode	Actual	% Loss of Original Electrode	Actual	% Gain of Original Electrode
1. Bare Electrode	No protection	0.14	88	0.30	60	0.105	2100
2. Covered Electrode, slag producing, long arc	Minimum protection from covered electrode	0.10	63	0.20	40	0.065	1300
3. Covered Electrode, slag producing, medium arc	Medium protection from covered electrode	0.06	37	0.14	28	0.045	900
4. Covered Electrode, slag producing, short arc	Maximum protection from covered electrode	0.05	31	0.09	18	0.022	440
5. Covered Electrode, slag producing, short arc and secondary protection	Maximum protection	0.05	31	0.07	14	0.013	260
6. Bare Electrode, gas protection	Good protection	0.08	50	0.00	00	0.026	520
7. Covered Electrode, gas producing type	Maximum protection	0.085	53	0.00	00	0.014	280

Table 4—Nitrogen and Oxygen Contents of Commercial Steels

Investigator	Material	Method of Analysis	Nitrogen	Oxygen	Carbon
Scott[3]	Bessemer Steels	Solution	0.010–0.024		
"	Electric Furnace Steels	"	0.010–0.024		
"	Open-Hearth Steels	"	0.003–0.008		
"	Crucible Steels	"	0.005–0.002		
Ziegler[2]	Armco Iron	Vacuum Fusion	0.021	0.057	
"	" "	" "		0.113	0.016
"	" "	" "		0.091	0.008
"	Electric Steel Forging	" "		0.015	1.0
"	Oxyacetylene Weld	" "	0.017	0.053	
"	Atomic-Hydrogen Weld	" "	0.013	0.054	
Grossmann	American Boiler Plate	" "	0.009	0.013	0.26
"	" " "	" "	0.008	0.011	0.22
"	German " "	" "	0.009	0.026	0.06
"	" " "	" "	0.009	0.021	0.06
"	Izett Steel	" "	0.011	0.018	0.13
"	" "	" "	0.011	0.015	0.18
Jordan-Swindells[4]	Bessemer Steel	Solution	0.012		
"	Electric Furnace Steels	"	0.005		
"	Spring Steel, Electric Furnace Steel	"	0.005–0.010		
"	Open-Hearth Steel	"	0.0024		
"	" " "	"	0.003		

of the weld metal resulting from changes in the length of the arc. Weld 5 is typical of a weld metal deposited with the maximum protection which can be practically attained by the combined use of a covered electrode of the slag-producing type and of a secondary protective envelope of reducing gas.

Weld 6 represents a weld metal deposited from a bare electrode, the arc of which has been protected by bathing in an atmosphere of hydrogen. While the loss in carbon in this case might be accounted for by combination of carbon and hydrogen, the presence of 0.031% nitrogen can only be explained by infiltration of air through the hydrogen envelope since the hydrogen gas used was free from nitrogen.

Weld 7 represents a typical analysis of weld metal, deposited from a covered electrode, the covering of which was made of a mixture of carbonaceous material and of mineral material, and is, therefore, partially gas producing and partially slag producing at the arc. Excellent protection of the weld metal has been secured by this type of electrode.

Based on an average analysis for the electrode of carbon 0.16, manganese 0.50 and nitrogen 0.005, the losses in carbon and manganese contents and gain in nitrogen content for the seven different weld metals are given in Table 3. The changes in chemical composition of the metal during its arc transfer are quite extreme, based on the per cent decrease or increase from the original composition of the electrode.

Table 2 indicates how readily the composition of a weld metal, and as a corollary, how readily the properties of a weld metal may be changed at will through a wide range. It should be appreciated that the analyses given for the seven different types of weld metals, while being actual analyses, are typical only for deposition under a particular set of conditions of the variable factors encountered in metal-arc welding, such as arc length, amperage, polarity, etc. Inasmuch as the deposition of a thick weld by the metal-arc involves the deposition of many feet of individual weld metal beads, the deposition extending over a considerable period of time and being subject to several variations in welding

[3] F. W. Scott, "Effect of Nitrogen on Steel," *Industrial and Engineering Chemistry*, 28, No. 9, p. 1036.

[4] Jordan and Swindells, "The Determination of Combined Nitrogen in Iron and Steel," *Bureau of Standards Sci. Paper* No. 457, Nov. 1922.

conditions throughout the interval, it should be appreciated that for any weld some departure from the typical analysis may be expected in the different beads of weld metal.

Indeed this inhomogeneity of weld metal may present a serious difficulty in obtaining exact data on a small number of test specimens, especially if the test specimens are of small dimensions. Examination of macrograph, Fig. 1, will give a better appreciation of this condition. It is evident that the weld metal is made up of at least two different materials:

1. The dark deeply corroded zones, constituting the bulk of the weld metal, and,
2. Two light colored less corroded zones at the bottom and center of the macro section.

If, then, a small specimen were taken from the central light colored zone, the properties obtained on this small specimen would certainly not be typical of the bulk of the weld metal. The differential etching of the weld of this macro section is due to variation in nitrogen content, the dark zones possessing higher nitrogen contents than the light, less corroded zones. Because of this relative lack of homogeneity in some weld metals, great caution must, therefore, be exercised in the interpretation of results.

Nitrogen content has been taken as the criterion by which the degree of protection of the weld metals from the gases of the atmosphere has been measured. This was not due to inappreciation of the rôle of oxygen in affecting the properties of steel, but was due to the difficulties encountered in securing oxygen determinations, and to an appreciation of the dangers involved in correctly interpreting the results of oxygen determinations. Accurate nitrogen determinations can be readily secured and, moreover, it is reasonable to suppose that a high nitrogen content is accompanied by a high oxygen content, and a low nitrogen content by a correspondingly low oxygen content. It is not claimed that the relationship may be expressed by a direct proportion, for in the case of covered electrodes the fluxing action of the slag would undoubtedly tend to remove some of the FeO formed. An examination of Table 2, however, will show that high nitrogen is accompanied by low carbon and manganese, while low nitrogen is accompanied by high carbon and manganese contents. These conditions would point to the veracity of the qualitative relationship between nitrogen and oxygen contents observed above.

Low-carbon metal-arc weld metals, according to the analyses presented, possess nitrogen contents from 0.015 to 0.155% and oxygen contents at least up to 0.259%. These values are abnormally high in comparison with the nitrogen and oxygen contents of any of the structural steels in use today. Even Weld Metal 5 of Table 2 with the lowest nitrogen content (0.015%) of the series possesses 300% more nitrogen than an average amount in steels of open-hearth manufacture. Oxygen and nitrogen values for several commercial steels obtained by various investigators are presented in Table 4.

Possessing the relatively high nitrogen and oxygen contents in comparison with those of the above steels of normal steel making practices, weld metals as materials for an investigation should offer some very interesting metallurgical aspects with respect to the study of steels of abnormally high nitrogen and oxygen contents, and to the general study of the effect of nitrogen and oxygen on the properties of steel.

Several items in Table 2 require some explanation. The evidence would indicate that the sulphur and phosphorus contents of weld metals are not decreased during the arc transfer. An attempt was made to determine the amounts of slag or non-metallics present in the various weld metals by obtaining the insoluble residues on dissolving the samples in iodine and in nitric acid. The insoluble residues obtained by the two methods check each other satisfactorily in most cases. It is quite evident that the nitride needle-like constituent is soluble in both methods. The insoluble residues of the weld metals deposited from covered electrodes are very much higher than those of Weld Metals 1 and 6 deposited from bare electrodes without and with the protective hydrogen atmosphere, respectively. The reason for this is evident, small slag inclusions from the fused covering being entrapped in the weld metals deposited from the covered electrodes. The values given for silicon in this table for the covered electrode welds do not represent actual silicon in solution in the ferrite as a silicide, but much of this probably comes from the entrapped slag particles. The nitrogen values of Table 2 were obtained by the modified Allen method of Jordan and Swindells[4] (acid solution method). The nitrogen obtained is combined nitrogen existing as nitride of iron. The nitrogen values, however, probably also represent total nitrogen, and probably the vacuum fusion method, by which total nitrogen, both molecular nitrogen and nitrogen as nitride is obtained, would give the same results, i.e., it is expected that in weld metal very little nitrogen is present in the molecular state.

Summary

Metal-arc weld metal as a generic name covers deposited metal of widely varying chemical composition, these variations being due to the number of variable factors entering into the deposition of weld metal. The term weld metal must, therefore, be used with suitable modifying and descriptive terms to define particular types of weld metals. This has been done in the present investigation by description of the electrode and length of the arc used in the deposition of a weld metal; for example, bare electrode weld metal; covered electrode—long arc weld metal; covered electrode—short arc weld metal, etc. This is equivalent to describing the weld metal by the degree of protection from contamination by atmospheric gases afforded the molten metal during its arc transfer. By varying the efficiency of the protection either by varying the nature and thickness of surface coatings and coverings or by changing the length of the arc, the composition of the deposited weld metal may be changed at will.

The nitrogen content of metal-arc weld metals may vary from 0.015 to 0.15, depending upon the degree of protection. Oxygen contents are also presumably high, although no oxygen determinations were made in this investigation, and nitrogen content has been considered as the criterion of the efficiency of protection. Other changes in chemical composition occur during weld deposition—the carbon and manganese being considerably lowered, the decrease in the contents of these elements from their values for the original electrodes being again dependent upon the degree of protection of the arc. The large loss of carbon and manganese in the transfer of the molten metal through the arc is indicative of the extremely oxidizing conditions within the arc.

It will be shown in later papers that these variations in chemical composition affect the nature and distribution of micro constituents of the various weld metals, and the behavior of these weld metals in their responses to varying heat treatments, and as a result the elastic properties and the behavior under plastic deformation of the various weld metals, not only at room temperature but throughout the entire temperature range, must be deeply affected.